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Book of Abstracts

the 6th International Conference
on Nanogenerators and Piezotronics

Book of Abstracts

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6th International Conference on Nanogenerators and Piezotronics
Sundsvall Sweden June 20–23 2022 MIUN 2021/2231

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Oral

1. Triboelectric nanogenerators

From Triboelectric Nanogenerators to Maxwell Equations for Mechano-Driven Slow-Moving Media Systems

1.1 Fundamentals

1. Triboelectric nanogenerators

Zhong Lin Wang[1]

[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences

From Triboelectric Nanogenerators to Maxwell Equations for Mechano-Driven Slow-Moving Media Systems

School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia USA

As inspired by the invention of the triboelectric nanogenerators (TENGs), interests on the study of electromagnetic behaviour of moving media have been revived. The conventional Maxwell's equations are for media whose boundaries and volumes are fixed. But for cases that involve moving media and time-dependent configuration, the equations have to be expanded. Here, starting from the integral form of the Maxwell's equations for general cases, we first derived the Maxwell's equations for a mechano-driven slow-moving medium by assuming that the medium is moving as a rigid translation object. Secondly, the expanded Maxwell's equations are further developed with including the polarization density term in displacement vector owing to electrostatic charges on medium surfaces as produced by effects such as triboelectrification, based on which the theory for TENGs is developed.

- L. Wang "From conctact electrication to triboelectric nanogenerators" (Review), *Report on Progress in Physics*, **84** (2021) 096502; https://doi.org/10.1088/1361-6633/ac0a50
- L. Wang "On the expanded Maxwell's equations for moving charged media system – general theory, mathematical solutions and applications in TENG", *Materials Today*; https://doi.org/10.1016/j.mattod.2021.10.027
- L. Wang, "On the first principle theory of nanaogenerators from Maxwell's equations", *Nano Energy*, **68** (2020) 104272; https://doi.org/10.1016/j.nanoen.2019.104272
- Shao, M. Willatzen*, and Z.L. Wang* "Theoretical modelling of triboelectric nanogenerators (TENGs)" （Review）, *J. Applied Physics*, **128** (2020) 111101; https://doi.org/10.1063/5.0020961

When: 2022-06-20, 14:35 - 14:50, Where: Parallel session 1

A New Triboelectric Nanogenerator with Excellent Electric Breakdown Self-Healing Performance

1.1 Fundamentals
1. Triboelectric nanogenerators

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Abstract text: Triboelectric nanogenerators (TENGs) have great potential to alleviate the energy crisis. TENGs can convert various mechanical energies into electrical energy. Compared with conventional electromagnetic generators (EMGs), TENGs have significantly higher efficiency in harvesting low-frequency mechanical energy, with the advantages of much lower cost and smaller size. However, TENGs suffer from unpredictable damage due to stretching, bending, compression, interfacial friction, electrical breakdown, etc. Materials with self-healing properties solve this problem well. In this study, a new TENG was developed based on a new type of polyurethane-based self-healing elastomer with good mechanical self-healing property (healing efficiency is about 96%) and excellent electric breakdown self-healing performance (healing efficiency is 90%). Self-healing mechanism study indicates that the excellent self-healing properties come from a combination of intermolecular hydrogen bonding, weak and dynamic coordination bonds between Fe^{3+} and pyridine rings. The developed TENG can generate an open-circuit voltage of 180 V, a short-circuit of 1.3 μA, and a maximum power of 40 $mW \cdot m^{-2}$. The developed TENG shows excellent stability (no output performance degrading even after a 3000 cycles). Interestingly, the output electrical properties of the developed TENG can be almost 100% restored to the original state before and after repeated mechanical self-healing or electrical breakdown self-healing.

When: 2022-06-20, 12:50 - 13:05, Where: Parallel session 1

Achieving Ultrahigh Output Energy Density of Triboelectric Nanogenerator in High-Pressure Gas Environment

1.1 Fundamentals

1. Triboelectric nanogenerators

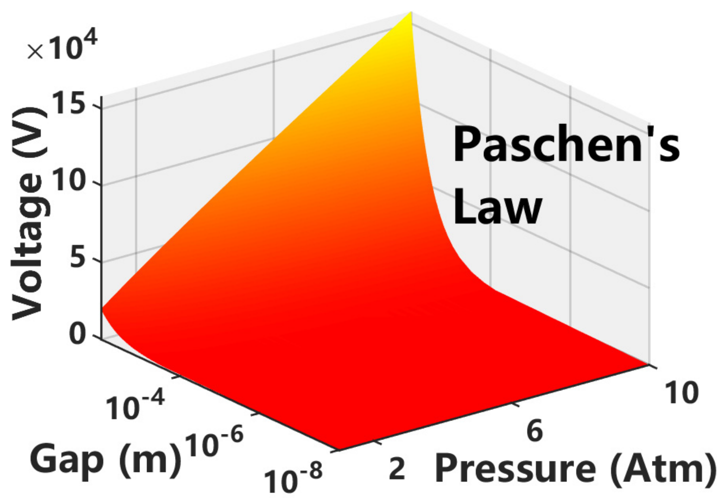
Jingjing Fu[1]

Yunlong Zi[1]

[1] The Chinese University of Hong Kong

Abstract text: Through years of development, the triboelectric nanogenerator (TENG) has been demonstrated as a burgeoning efficient energy harvester. Plenty of efforts have been devoted to further improving the electric output performance through material/surface optimization, ion implantation or the external electric circuit. However, all these methods cannot break through the fundamental limitation brought by the inevitable electrical breakdown effect, and thus the output energy density is restricted. Here we proposed a method for enhancing the threshold output energy density of TENGs by suppressing the breakdown effects in the high-pressure gas environment. With that, the output energy density of the contact-separation mode TENG can be increased by over 25 times in 10 atm than that in the atmosphere, and that of the freestanding sliding TENG can also achieve over 5 times increase in 6 atm. Our research demonstrated the excellent suppression effect of the electric breakdown brought by the high-pressure gas environment, which may provide a practical and effective technological route to promote the output performance of TENGs.

Selected references



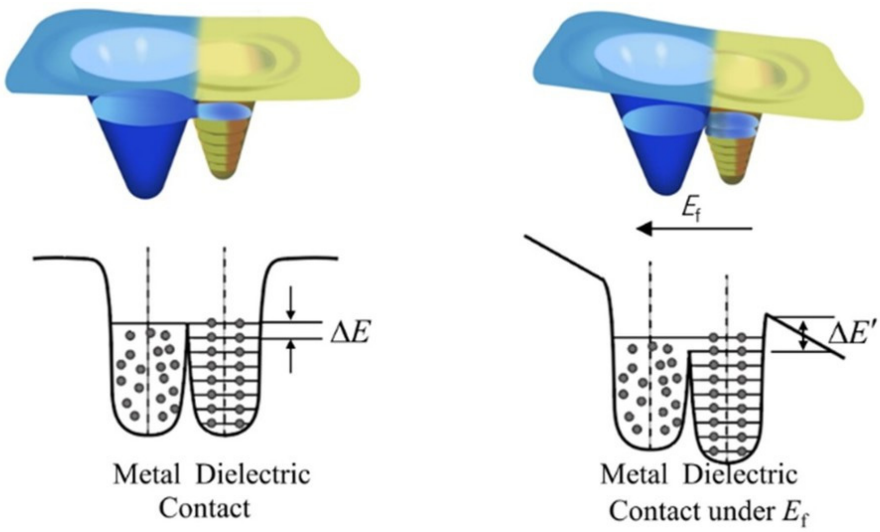
When: 2022-06-20, 13:05 - 13:20, Where: Parallel session 1

Density of Surface States: Another Key Contributing Factor in Triboelectric Charge Generation

1.1 Fundamentals
1. Triboelectric nanogenerators

Guoqiang Xu
yunlong zi[1]
[1] The chinese university of hong kong

Abstract text: The triboelectric nanogenerator (TENG) has been invented as a new technology for harvesting mechanical energy, with enormous advantages. The charge generation of the TENG is mainly related to the triboelectric effect or contact electrification (CE) as usually described by the potential-well-electron-cloud model, while the triboelectric charge transfer is related to the difference in the occupied energy levels of electrons. However, in our experiment, we observed abnormal triboelectric charge generation phenomena between ternary materials, which cannot be explained by the occupied energy level difference only. To address this issue, we proposed the model based on the density of surface states (DOSS) as another key contributing factor to the triboelectric charge generation. To demonstrate our model, we introduced an approach to measure the DOSS through applying external electric field between two triboelectric surfaces. Our experiments confirmed the contribution of the DOSS to the triboelectric charge generation, which verified our model. This study provides another key contributing factor to the triboelectric charge generation, which may provide a more complete model for guiding the material selection to tailor the surface charge generated by the CE.



When: 2022-06-20, 12:00 - 12:25, Where: Parallel session 1

The self-powered nanosystem based on triboelectric nanogenerator and smart materials

1.1 Fundamentals
1. Triboelectric nanogenerators

Xiangyu Chen[1]
[1] Beijing Institute of nanoenergy and nanosystems, Chinese Academic of Sciences, Beijing, China

Abstract text: For this presentation, we outline the latest developments of the self-powered systems and sensors based on TENG and we also provide a clear understanding of the key factors that decide whether the chosen materials or devices can be successfully combined with TENG. In the first segment of the presentation, we give an in-depth introduction of the successful approaches taken for achieving high voltage of TENG. In the subsequent parts, we give a detailed overview of the electrically responsive materials and electrostatic devices that can be effectively combined with TENG, including dielectric elastomer, piezoelectric materials, ferroelectric materials, electrostatic manipulator, electrostatic air cleaner and field emission/mass spectrometer. Finally, a broader perspective and the recommend future research directions are discussed to conclude the presentation.

When: 2022-06-20, 12:25 - 12:50, Where: Parallel session 1

A dynamic model of electromechanical conversion based on TENG and the related application

1.1 Fundamentals
1. Triboelectric nanogenerators

Yi Xi[1]
[1] Chongqing University

Abstract text: Intelligent warning and monitoring are very important for public safety and environmental protection. However, most of the proposed self-powered devices based on triboelectric nanogenerator (TENG) face the challenge of stability and micro-vibration. Moreover, TENG guided by the theory of fluid dynamics needs further exploration. Herein, a dynamic model is proposed to study the intrinsic interaction between the electrical properties of TENG and fluid dynamics of gas and liquid, and a low frequency random micro-vibrational self-powered device in all directions and a wide working bandwidth is fabricated. This work can provide a direction for in-depth understanding of the electromechanical conversion mechanism, and application of TENG in self-powered sensors of micro-vibration.

When: 2022-06-20, 14:10 - 14:35, Where: Parallel session 1

Cellulose as a triboelectric material

1.1 Fundamentals

1. Triboelectric nanogenerators

Magnus Norgren[1]

Christina Dahlström[1], Alireza Eivazi[1], **Haider Iftikhar**[2], Orlando Rojas[3], Bruno Medronho[4], Renyun Zhang[1]

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[2] Department of Bioproducts and Biosystems, Aalto University, Aalto, Finland

[3] Chemical and Biological Engineering, University of British Columbia, Vancouver, Canada

[4] MED - Mediterranean Institute for Agriculture, Environment and Development University of Algarve, Faro, Portugal

Abstract text: To date, seven polymorphic forms of cellulose that are interconvertible have been identified, where cellulose II is the most thermodynamically stable polymorph. A remarkable increase in static charging has been observed when transforming cellulose from the natural polymorph cellulose I into man-made cellulose II that is obtained via dissolution and regeneration. There is a striking knowledge gap within the research area when it comes to organic materials like polymers, and the concomitant triboelectric description, which is not consistent. Since the invention by Z.L. Wang in 2012, the research on TENGs has been continuously driven by designing different material combinations and breaking new records in power output. Much can be learned and adopted from this when developing new devices. However, to better understand, describe and utilize polymer materials the area needs more systematic studies. There are several surface chemical and structural parameters that can change the order in the triboelectric series between polymeric tribo-materials. Moreover, even within "the same" polymer material, the placement in the tribo-series can alternate due to relatively small chemical and physical differences that are changing the basis for interfacial polarization. This is especially true for a semicrystalline and easily surface derivatized materials such as cellulose that can also exist structurally different; as fibers, micro and nano fibrils, as well as regenerated from the solution state dispersions. In this paper we discuss some findings regarding cellulose that are important for the triboelectric performance.

When: 2022-06-21, 09:35 - 10:00, Where: Parallel session 1

Fundamental mechanism of mechano-electronic excitation and DC transport at dynamic semiconductor heterojunctions

1.1 Fundamentals

1. Triboelectric nanogenerators

Jun Liu[1]

[1] University at Buffalo, The State University of New York

Abstract text: As Internet of Things (IoTs) has come of age, power sources are expected to be more miniaturized, sustainable, and self-adaptive, bringing new challenges to ambient energy harvesting technologies. Dynamic Schottky DC generator holds great promise for ambient mechanical energy harvesting as it overcomes the low-current output limitation in conventional approaches by generating a continuous DC output with a large current density, which has also been refereed as 'tribovoltaic' effect in analogy with photovoltaic effect. The last few years have witnessed a significant progress on the improvement of the DC power output and robustness. In this talk, we will discuss the origin of the DC generation at sliding semiconductor heterojunctions with theoretical models and experimental evidence. The theoretical discussion will involve different perspectives including quantum mechanical and electrostatic point of view. In addition, we will discuss the knowledge gap of the current mechanism studies, where multi-physics couplings are involved, as well as future promises and challenges for different practical applications on energy and sensing.

When: 2022-06-20, 13:45 - 14:10, Where: Parallel session 1

High-Performance Triboelectric Nanogenerator and Tribophotonics

1.1 Fundamentals

1. Triboelectric nanogenerators

Yunlong Zi[1, 2]

[1] The Chinese University of Hong Kong

[2] Hong Kong University of Science and Technology (Guangzhou)

Abstract text: As the development of the Internet of Things (IoT), trillions of widely-distributed devices are integrated for health monitoring, biomedical sensing, environmental protection, infrastructure monitoring, and security, which require power supplies. To provide a sustainable power solution, triboelectric nanogenerator (TENG) has been developed since 2012 for high-efficiency mechanical energy harvesting from the ambient environment. The PI's team has made significant contributions to fundamental studies about the triboelectric effect, discharge, and TENG output characteristics. and Multiple strategies to greatly enhance the output performance of TENG has been demonstrated, such as the high-pressure environment and the liquid-solid interface. On the other hand, the PI's team also proposed and developed the concept of tribophotonics: tribo-charge induced tuning or generation of photons toward self-powered wireless sensing, which can be achieved through tunable liquid lens, liquid crystal, optical switch, tribo-induced electroluminescence (TIEL), and discharge. These studies will drive the further development of TENG technology for broad applications in blue energy harvesting, the IoT, human-machine interface, health & infrastructure monitoring, wearable & implantable electronics, towards high-efficiency self-powered systems.

When: 2022-06-21, 09:05 - 09:20, Where: Parallel session 1

Highly positive triboelectric material induced by controlling local dipole

1.1 Fundamentals

1. Triboelectric nanogenerators

Donghyeon Kang[1]

Jihye Kim[1], Sang-Woo Kim[1]

[1] School of Advanced Materials Science and Engineering, Sungkyunkwan University (SKKU), Suwon, Kyunggi-do 440-746, South Korea

Abstract text: The development of positive triboelectric materials is highly required for realizing durable and high-performance triboelectric generators. Here, we introduce a novel protocol to maximize local dipole for designing highly positive triboelectric material and propose strong electronegative and low electron affinity atoms-based dimethylol urea, diazolidinyl urea, and imidazolidinyl urea as a promising positive triboelectric material using our design protocol. A mechanism that the highly positive triboelectric material has triboelectric properties was investigated using the combination of electronegativity and negative local dipole formed on the highest occupied molecular orbital (HOMO-) consisting of non-bonding electrons. Negative local dipole (δ-) is formed by the electron accumulation around the high electronegative and low electron affinity atoms (e.g. nitrogen, oxygen except for fluorine which has the highest electron affinity), which attract electrons from bonded atoms and tend to donate its electrons to atoms in other materials, and thus negative local dipole creates the electron-donating environment. We confirm design protocol using CPD, triboelectric output, and DFT calculation. KPFM demonstrated that DMU, DU, and IU has more positive surface potential than nylon. We realized a high-performance triboelectric generator also measures the triboelectric output of DMU, DU, and IU when in contact with PTFE, it has a higher electrical output than nylon when in contact with PTFE.

When: 2022-06-21, 08:50 - 09:05, Where: Parallel session 1

Highly-stable 2D-layered halide perovskite embedded in a polymer matrix for development of robust nanogenerator

1.1 Fundamentals
1. Triboelectric nanogenerators

Swathi Ippili[1]
Venkatraju Jella[1], Soon-Gil Yoon[1]
[1] Department of Materials Science and Engineering, Chungnam National University, Daeduk Science Town, 305-764, Daejeon, South Korea.

Abstract text: With burgeoning attention on wearable, portable, and wireless electronic devices, the demand for sustainable and portable electrical power sources is continuously increasing. To overcome the limitations of batteries, various harvesters that can convert ambient energies such as solar, thermal, mechanical energy into electrical energy have been developed. Mechanical energy is one of the largest sources of wasted energy and can be harvested using piezoelectric, triboelectric nanogenerators (TENGs) and etc. Among the various nanogenerators, TENGs have garnered great attention because of their high output power and cost-effective fabrication routes. TENG efficiency depends on several parameters including material, surface treatment, and dielectric constants. Halide perovskites (HPs) have lately been explored towards mechanical energy harvesting applications due to their decent dielectric and piezoelectric properties. Moreover, the HP materials have been utilized as fillers in poly(vinylidene fluoride) (PVDF) matrix to improve the electroactive β-phase, dielectric and piezoelectric properties of PVDF.

Herein, we present a high-performance and robust TENG based on moisture-stable $DAPPbI_4$–PVDF composite material to harvest mechanical energy. Where the fabricated $DAPPbI_4$–PVDF composite film serves as negative triboelectric materials, and their dielectric polarization and electroactive β-phase were controlled by perovskite addition. The output performance of TENG was gradually improved with increasing perovskite loading and attained higher for 15 wt% TENG with an output voltage of ~670 V and power-density of ~4.3 mW/cm^2. Further, the same device was used to charge the conventional V_2O_5 based Li-ion battery to realize the self-charging power unit (SPU). The developed SPU was utilized to continuously operate small-scale electronic devices.

When: 2022-06-21, 10:25 - 10:40, Where: Parallel session 1

Investigation on the Origin of Tribo-negative Nature of Polytetrafluoroethylene: First-Principles Study

1.1 Fundamentals
1. Triboelectric nanogenerators

Sera Jeon[1]
Dabin Kim[1], Sang-Woo Kim[1]
[1] School of Advanced Materials Science and Engineering, Sungkyunkwan University, Suwon 16419, Republic of Korea

Abstract text: Triboelectric nanogenerator (TENG) is an energy harvesting device that converts mechanical energy into electricity based on the coupling of contact electrification and electrostatic induction. Fluorocarbon polymers, such as polytetrafluoroethylene (PTFE) and perfluoroalkoxy alkane (PFA) are the widely used polymeric triboelectric materials, however, their tribo-negative nature has been poorly understood. Here, using first-principles calculations, we have systematically investigated the electronic structure of PTFE and PFA. It is revealed that the defects associated with carbon dangling bonds act as charge trapping centers during contact electrification. Furthermore, the simulation on the contact model of PTFE and nylon confirms that the charge transfer occurs when the distance between them is as near as the atomic orbitals overlap. In addition, the calculated work functions of polymeric materials are consistent with the triboelectric series, giving a powerful method to predict the triboelectric property of materials. We expect our study provides fundamental understandings on the origin of the triboelectric property of materials and the atomistic phenomena during contact electrification. Our results also give insight into triboelectric material designs with a strong electron-withdrawing property.

When: 2022-06-22, 13:45 - 14:10, Where: Parallel session 2

The impact of free carriers and surface traps on semiconducting piezoelectric devices

1.1 Fundamentals
1. Triboelectric nanogenerators

Gustavo Ardila[1]
[1] Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, Grenoble INP, IMEP-LaHC, F-38000 Grenoble, France

Abstract text: Piezoelectric thin films are widely used in MEMS and NEMS actuators and resonators, as well as in mechanical sensors and energy harvesters for IoT applications or Wireless Sensors Networks (WSN) [1] Nanotechnology involving piezoelectric materials has been identified by the European Community and International Technological Roadmaps as a key research direction [2], with benefits expected from nanostructuring and the replacement of toxic materials. Piezoelectric nanocomposites based on semiconducting nanowires (NWs) are an alternative to thin films with benefits expected from nanostructuration, such as low temperature fabrication and higher flexibility than their thin film counterparts. Higher piezoelectric coefficients have also been reported at the nanoscale [3]. Vertically grown NWs, embedded into an insulating matrix, are a typical example of such nanocomposite. In this presentation, we will discuss the modelling and experimental issues, with special focus on the introduction of surface traps and free carriers in the simulation of thin films and nanocomposites of ZnO [4]. The influence of growth method (affecting doping and surface traps), geometry, as well as comparison with a thin film of same thickness, will be presented in more detail [5].

References:

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- Ahopelto et al., Solid-State Electronics 155, 7 (2019)
- M Minary-Jolandan et al., Nano letters 12, 970 (2012)
- Tao et al., Advanced Electronic Materials 4, 1700299 (2018)
- J. Lopez Garcia et al., Nanomaterials 11, 941 (2021)

When: 2022-06-21, 08:25 - 08:50, Where: Parallel session 1

Theory and Optimization of Spherical Nanogenerators

1.1 Fundamentals

1. Triboelectric nanogenerators

Morten Willatzen[1]

Jens Gravesen[2], Jiajia Shao[1], Zhong Lin Wang[1]

[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences

[2] DTU Compute, Technical University of Denmark

Abstract text: A fundamental theory of 3D generic triboelectric nanogenerators is presented and applied to spherical nanogenerators. General geometric definitions of triboelectric nanogenerator capacitance, potential, and power output are derived in a dimensionless formulation. Comparison with the capacitance of standard circular plate TENGs shows good agreement. The system framework is applied to optimize model parameters of two symmetrically placed spherical-cap shaped electrodes and charged dielectrics plus an additional oscillating dielectric sphere of opposite charging to ensure TENG overall charge neutrality.

Reference:

[1] Jens Gravesen, Morten Willatzen, Jiajia Shao, and Zhong Lin Wang, "Energy Optimization of a Mirror-Symmetric Spherical Triboelectric Nanogenerator," Adv. Funct. Mater. **2022**, 2110516.

When: 2022-06-21, 08:00 - 08:25, Where: Parallel session 1

Understanding Contact Electrification at Liquid-Solid Interfaces from Surface Electronic Structure

1.1 Fundamentals
1. Triboelectric nanogenerators
Bolong Huang

Abstract text: The triboelectric effect, which is also known as contact electrification (CE)-related electrostatic phenomena, is the most common situation that occurred in the ambient environment, from simple walking to even thunderstorms. The energy involved in this phenomenon has usually been ignored. Moreover, based on the concept of CE, the triboelectric nanogenerator (TENG) has been invented to couple the triboelectrification and electrostatic effect for efficient energy harvesting and conversion, leading to a promising field of sustainable and renewable self-power electronic devices. Recently, the liquid-solid interaction dominated electricity generation becomes the research interest of the scientific community, especially the involved electron transfer behaviors. We have investigated the contact electrification mechanism at the liquid-solid interface from the atomic perspective regarding the electronic structure. The electronic structures display stronger modulations by the outmost shell charge transfer via surface electrostatic charge perturbation than the inter-bonding-orbital charge transfer at the liquid-solid interface. This supports more factors being involved in charge transfer during the contact electrification. Meanwhile, we introduce the electrochemical cell model to quantify the charge transfer based on the pinning factor to linearly correlate the charge transfer and the electronic structures. The pinning factor exhibits a more direct visualization of the charge transfer at the liquid-solid interface. Our theoretical investigations aim to supply some references in describing, quantifying, and modulating the contact electrification-driven triboelectric nanogenerators in future works.

When: 2022-06-21, 10:40 - 10:55, Where: Parallel session 1

Achieving ultrahigh instantaneous power by leveraging the opposite-charge-enhanced transistor-like triboelectric nanogenerator (OCT-TENG)

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Hao Wu[1]
[1] South China University of Technology

Abstract text: Being able to convert low-frequency ambient mechanical energy into electricity, triboelectric nanogenerator (TENG) has attracted worldwide attention. Like all the energy harvesting technologies, high power output has always been pursued, also for TENG. In this report, I will introduce our work on achieving ultrahigh power output in a TENG device by leveraging the opposite-charge-enhancement effect and the transistor-like device design. On the one hand, we enhance the amount of charge transfer by the opposite-charge-enhancement design. On the other hand, we decrease the output impedance of the TENG to close to zero by using a switch-like design (we also vividly call it a "transistor-like" design). In such a way, instantaneous power density over 10 MW/m^2 has been achieved at a low frequency of ~ 1 Hz. The average power density of 790 $mW \cdot m^{-2} \cdot Hz^{-1}$ of our TENG is also higher than the previous reports. We show that 180 W commercial lamps can be lighted by a TENG device. A vehicle bulb containing LEDs rated 30 W is also wirelessly powered and able to illuminate objects further than 0.9 meters away. Our results demonstrate the possibility of using TENG to power the broad practical electrical appliances[1].

Reference:
[1] Wu, H., Wang, S., Wang, Z. Zi, Y. Achieving ultrahigh instantaneous power density of 10 MW/m^2 by leveraging the opposite-charge-enhanced transistor-like triboelectric nanogenerator (OCT-TENG). *Nat Commun* **12,** 5470 (2021).

When: 2022-06-21, 10:00 - 10:25, Where: Parallel session 1

Cellulose-based high performance triboelectric nanogenerators

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Renyun Zhang[1]
[1] Mid Sweden University

Abstract text: Triboelectric nanogenerators (TENGs) have attracted increasing attention because of their excellent energy conversion efficiency, diverse choice of materials, and broad applications in energy harvesting devices and self-powered sensors. New materials have been explored, including green materials, but their performances have not yet reached the level of that for fluoropolymers. We have recently found that regenerated cellulose materials can have strong triboelectric effects. Taking advantage of the strong triboelectric effect, we have fabricated high-performance, fully green TENGs (FG-TENGs) using cellulose-based tribo-layers with an output power density of above 300 W m^{-2} that is a new record of green material-based TENGs.

Reference

Zhang, R. *et al.* Cellulose-Based Fully Green Triboelectric Nanogenerators with Output Power Density of 300 W m −2. *Adv. Mater.* **32**, 2002824 (2020).

When: 2022-06-20, 12:00 - 12:25, Where: Parallel session 3

Direct-current triboelectric nanogenerators based on electrostatic breakdown

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Di Liu[1]
Zhihao Zhao[1], **Jie Wang**[1], Zhong Lin Wang[1, 2]
[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences
[2] School of Materials Science and Engineering, Georgia Institute of Technology

Abstract text: With the rapid development of the Internet of Thing (IoT) era, it brings higher demands on new-era electric power supply system. Unimaginable complex distributed arrays of electronics and sensors will be employed to support the operation of IoTs, which is great challenge to traditional concentrated power supply system. The distributed power supply system is a potential approach to solve this problem. Triboelectric nanogenerator (TENG) represents a core group of technologies supporting the distributed electric power supply system, and its facile processability, multi-functionality, low cost and high efficiency at low operation frequency make it easily integrated within difference electronics. Here, I will talk about up-to-date accomplishments about the development of TENG with special focus on the new-type direct current TENG (DC-TENG) based on electrostatic breakdown. The internal mechanism of DC-TENG and its performance limitation factors will be also presented. Several methods to enhance its output performance, containing material selection and structural design, will also be discussed.

When: 2022-06-20, 12:50 - 13:05, Where: Parallel session 3

Boosting current output of triboelectric nanogenerator by two orders of magnitude via hindering interfacial charge recombination

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Irum Firdous[1]

Muhammad Fahim[1], Lingyun Wang[1], Wen Jung Li[1], Yunlong Zi[2], Walid A. Daoud[1]

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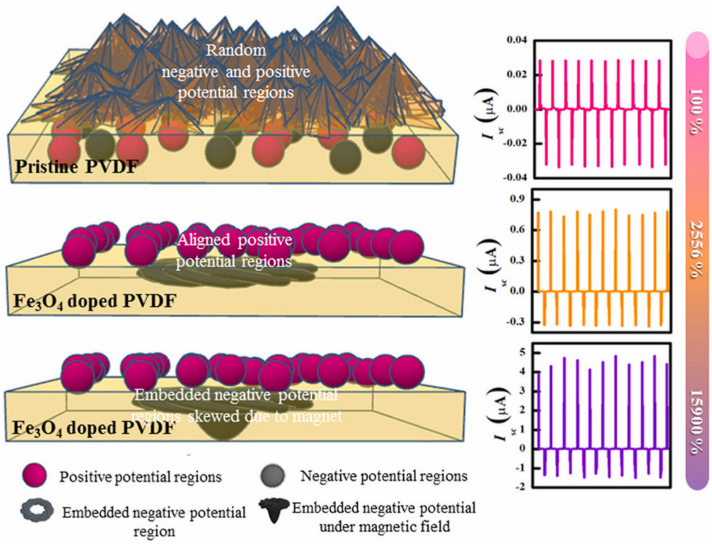
[2] Department of Mechanical and Automation Engineering, Chinese University of Hong Kong, Hong Kong

Abstract text: The performance of triboelectric nanogenerator is limited by interfacial charge losses due to alternate charge transfer. This is usually suppressed by addition of electron blocking, electron transporting layers or through external excitation. However, these approaches screen only electrons from the interface while the unstable positive charges remain. Herein, we report a stable tribopositive layer with an overall positive surface and embedded magnetic active negative centers for stabilizing positive charges to prevent cation recombination with anion of counterpart. Besides, a counterpart with high electron delocalization density is used for screening interfacial negative charges, leading to enhanced charge accumulation of 11 nC with short circuit current of 0.8 μA, increasing to 54 nC and 17.4 μA by staking 4 units of 2.25 cm² device in alternate layered structure, with an enhancement rate of 15.1 nC and 5.6 μA per unit. Further, the embedded negative centers in response to magnetic field form skewed charge transporting channels, causing homogeneous distribution of potential on the tribopositive layer, effectively transporting charges to electrode via hindering bulk losses. The single unit shows 15,900% enhancement reaching 4.8 μA, 208 μC m⁻² and 1.66 W m⁻² and demonstrating the highest enhancement capacity compared to previously reported strategies and thus a promising potential for wearable electronics with high power demand.



When: 2022-06-21, 13:05 - 13:20, Where: Parallel session 1

Electrostatically triggered autonomous self-healable and stretchable hydrogel for wearable electronics

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Irum Firdous[1]

Muhammad Fahim[1], Walid A. Daoud[1]

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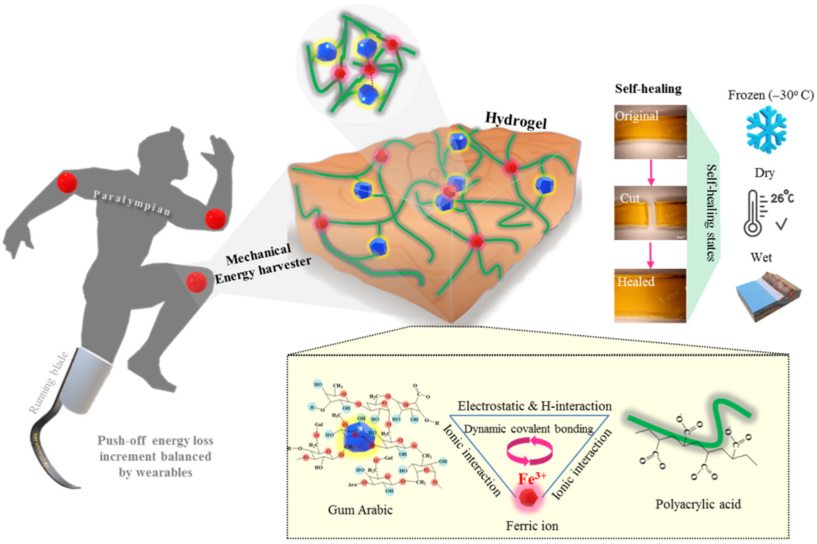
Abstract text: The expeditious growth of self-healable multifunctional electronics poses a challenge on power devices to acquire fast autonomous self-healing of solids with efficient electrical recovery. However, realizing this goal remains elusive due to the sluggish dynamics of covalent and ionically linked ions. Herein, we overcome this limitation by importing electrostatic and hydrogen bonding centers in solids to accelerate ion dynamics via more delocalization centers. As such, the matrix is able to retain fast autonomous self-healing characteristics in dry, wet, and frozen states via an electrostatically driven diffusion-less self-healing mechanism. The self-healable, stretchable, transparent hydrogel renders a triboelectric nanogenerator on contact with skin with the highest peak power density of 8 W m^{-2} (peak current of 15 μA) and the lowest internal resistance of 14 MΩ among the reported self-healable solid induction devices. The design strategy of combining charge and electrostatic interaction-driven self-healing property can be further extended to prosthetics, robotics, cryogenics, and sportswear-based wearable electronics.



When: 2022-06-21, 12:50 - 13:05, Where: Parallel session 1

Energy scavenging from the mechanical resource using piezoelectric and triboelectric nanogenerators

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Dong-Myeong Shin[1]
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Abstract text: In the era of the internet of things, the billions of connected devices will require not only high battery cost but also an enormous scale of maintenance expenses, so that we need an alternative for powering the devices beyond plugging all of the intelligent devices into the grid. The power supply for future technology requires independent, sustainable, continuous operation, and maintenance-free. The possible solution for easily powering those devices includes harvesting the tiny energy when available, from environmentally friendly sources like the sun, thermal, and mechanical energy. Our recent research interest has been dedicated to the developing the main components of self-powered nanoelectronics, which includes the energy harvesting and storage devices. In this talk, I will address a simple strategy for energy harvesting from mechanical energy based on the smart piezoelectric nanomaterials, such as ZnO nanorods/graphene/ZnO nanorods heterostructure and aligned M13 bacteriophage, as well as triboelectric nanomaterials. Further I will present the future energy storage technology based on a single-ion conducting electrolyte to improve the power density, safety concerns as well as high capacity retention at rapid discharging.

Ferroelectrically augmented triboelectricity enables efficient acoustic energy transfer through liquid and solid media

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Hyun Soo Kim[1, 2]

Sunghoon Hur[1], Chong-Yun Kang[1, 3], Jong Hoon Jung[2], Hyun-Cheol Song[1]

[1] Korea Institute of Science and Technoloy

[2] Inha University

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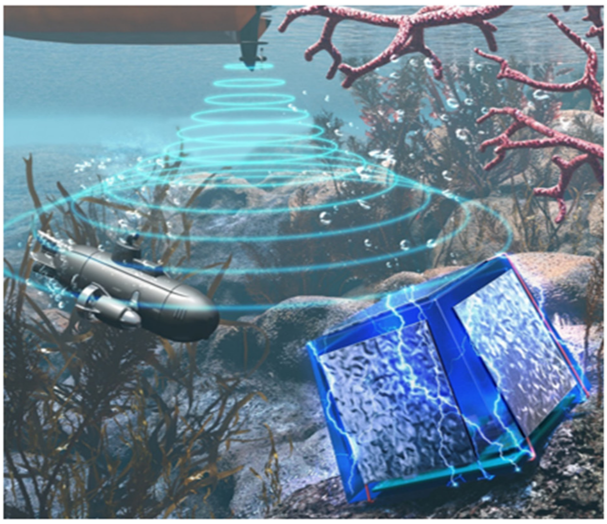
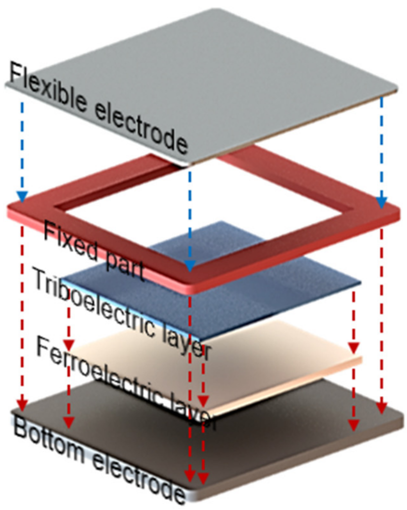
Abstract text: As demands for portable electronic devices grow, wireless energy transfer (WET) has started to become readily available. Until now, studies on WET have been mainly based on the electromagnetic (EM) induction method using EM waves. However, it is still challenging to utilize current EM wave mediated WET in those areas where it is most needed: underwater, body-implant, and EM-shielded cases (liquid/metals). Acoustic energy transfer (AET) can be an alternative to EM-wave based WET. Here, we present a simple but powerful triboelectric AET module by tuning the work function of the triboelectric layer via the large polarization of the embedded relaxor single crystal. Additionally, uniform displacement, a quasi-mode oscillation, across the flexible electrode surface in response to the square wave has improved energy transfer efficiency. A systematic investigation was conducted for energy transferring conditions of receiving angle and ferroelectric polarization. We successfully demonstrated the transmission of 8 mW electric power at a distance of 6 cm underwater, which is sufficient to use in most demanding but inaccessible areas. In addition, AET is demonstrated and discussed in both liquids (underwater and in-body), and solids (metal, wood, and plastic). We anticipate that our approach will enable current next-level AET technology to be utilized in the actual field.





When: 2022-06-21, 14:10 - 14:25, Where: Parallel session 1

High performance triboelectric nanogenerators based on electrospun PVDF-HFP/liquid metal nanofibre membrane

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Jin Zhang[1]
Zhao Sha[1]
[1] School of Mechanical and Manufacturing Engineering, University of New South Wales

Abstract text: The current investigation studies the influence of addition of liquid metal (LM) Galinstan nanodroplets into PVDF-co-hexafluoropropylene (PVDF-HFP) electrospun nanofibres on the triboelectric performance of its constituted nanogenerators. The peak open-circuit voltage and power density of the triboelectric nanogenerator (TENG) reached 1680 V and 24 W/m^2, respectively, when the PVDF-HFP/2%LM nanofibre membrane was used as the negative tribo-layer and the thermoplastic polyurethane film was used as the positive tribo-layer. The high performance is attributed from multiple factors, including the improved surface potential, capacitance, charge trapping capability, and the secondary polarization inside PVDF-HFP nanofibre by the introduced LM nanodroplets. The LM modified PVDF-HFP nanofibre membranes are promising materials in flexible TENGs as the negative tribo-layer.

When: 2022-06-21, 14:25 - 14:40, Where: Parallel session 1

Hybridizing triboelectric and thermomagnetic effects: a novel low-grade thermal energy harvesting technology

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Cátia Rodrigues[1]
Ana Pires[1], Isabel Gonçalves[1], Daniel Silva[1], Joana Oliveira[2], André Pereira[1], João Ventura[1]
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[2] LAETA/INEGI and Faculty of Engineering of the University of Porto, Department of Engineering Physics, Portugal

Abstract text: Energy has been one of the major driving forces behind our societal development and economic growth. However, the resulting surge in energy demand has also led to the major environmental crisis we now face. Thus, new energy generation technologies able to convert low-grade thermal energy into electricity are urgent to tackle the continuous surge in energy demand. In this work, a hybrid device that couples triboelectric and thermomagnetic effects to generate electrical power in the presence of small temperature gradients near room temperature was demonstrated. The thermomagnetic effect allowed to induce the periodic and sustained motion of a second-order ferromagnetic material in temperature gradients below 30 °C. This mechanical motion was converted into electrical energy using a triboelectric nanogenerator (TENG). The applicability of this concept was demonstrated in a broad range of operating temperatures in both the cold (15 to 37 °C) and hot (60 to 90 °C) sides. Varying the temperature gradients with TENG assembled in the cold-side, a maximum power density of 18 mWm^{-2} was reached using a cold- and hot-sides temperature of 30 and 65 °C. When assembled in the hot-side, TENG generated a maximum power density of 54.7 mWm^{-2} for cold- and hot-side temperature of ~20 and 65 °C. It was further shown that the electrical power generated by the hybrid TENG is more than 35× higher than that obtained by a conventional thermomagnetic generator. This work showed that TENGs is a high-efficient harvesting technology to use temperature differences and vibration mechanical energy as energy sources.

When: 2022-06-22, 08:30 - 08:45, Where: Parallel session 1

Performance enhancement of triboelectric nanogenerator through hole and electron blocking layers-based interfacial design

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

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Muhammad Fahim[1], Walid A. Daoud[1]
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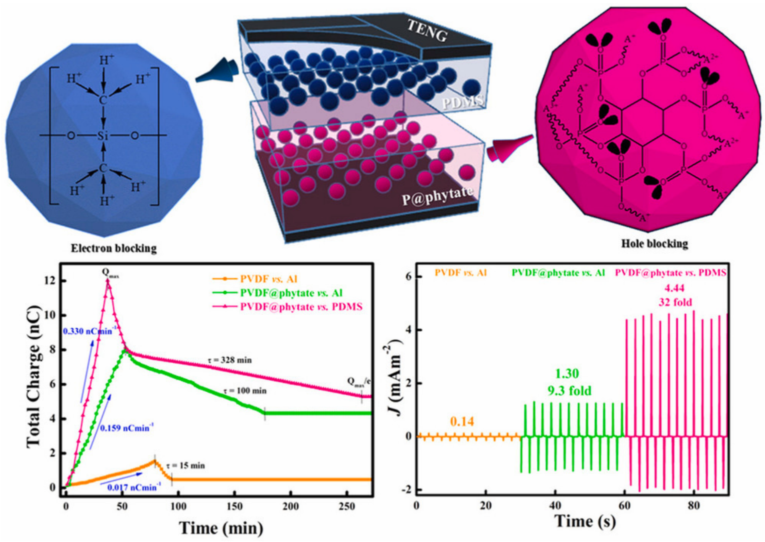
Abstract text: Enhancing negative charge retention sites on a contact surface is a key parameter to boost the performance of triboelectric nanogenerators. However, the unstable positive charge on the other contact surface can also be transferred as all surfaces have both charge donating and accepting regions. To prevent alternate charge transfer and charge recombination, PVDF is doped with phytate ion cluster as the tribopositive layer to trap positive charges through the formation of 18 hydrogen bonds or chelation through mono, di and trivalent cations of the 12 reactive phosphate groups, resulting in a 9.3-fold increase in current density. Moreover, the tribonegative layer is optimized with deeper trap states and more localization of negative charge (i.e. PDMS), which keeps tribocharges for longer duration of 5.5 h and results in a further 32-fold increase in current density to 4.4 mA m^{-2}. With the intrinsic charge trap enhancement, the device possesses high mechanical stability and durability, where the output performance remains intact after 16 month storage, due to the excellent compatibility of PVDF with phytate. Moreover, when four units of the device are stacked in parallel alternate layered form, an increase in output current from 1.1 μA to 20.9 μA with power density 0.80 W m^{-2} was obtained, displaying potential of the device design for powering high demand wearable electronics.



When: 2022-06-22, 08:15 - 08:30, Where: Parallel session 1

Porous PDMS conformable coating for high power output carbon fibers-based single electrode triboelectric energy harvesters

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Raquel Barras[1]

Andreia dos Santos[1, 2], Elvira Fortunato[1], Rodrigo Martins[1], Hugo Águas[1], Rui Igreja[1], Pedro Barquinha[1], Luís Pereira[1, 2]

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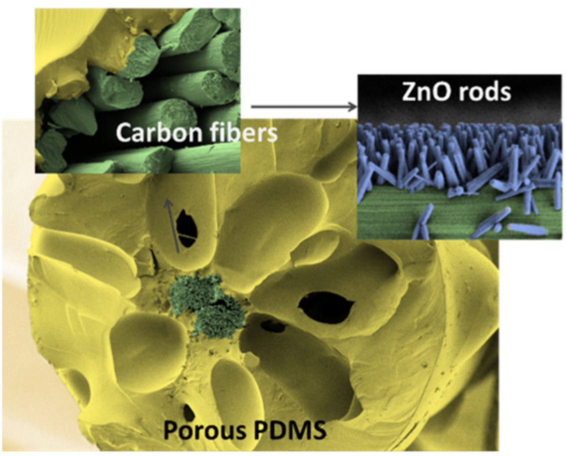
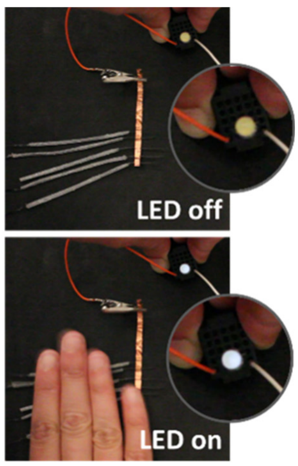
Abstract text: A new method for depositing PDMS directly onto conductive carbon yarns is proposed to produce Triboelectric Generator Yarns (TEG yarns). The in-situ PDMS curing method described in this study allows the fast formation of a uniform thick coating over conductive surfaces regardless of their roughness. Single-electrode configuration TEG yarns are developed and their electrical output is optimized by precisely adjusting the PDMS layer thickness and by changing the chemical and physical nature of the carbon fiber (CF) yarns' surface. Functionalizing the CF yarns' surface with ZnO rods combined with porous PDMS coating can enhance their electrical output. The best results achieved using this type of TENG yarns with an average diameter of 1.74 mm, which can be obtained after only 3 min of PMDS deposition by "*in-situ*" curing method. A maximum of 72 V peak-to-peak and 10 μA (74.1 μW cm^{-2} of power density with a load resistance of 20 MΩ) is reached when applying an impact force of 600 N to a set of five TENG yarns connected in parallel. The output is stable even after 10,000 cycles and this set of TENG yarns is also able to light at least 28 LEDs when tapping by hand, proving a contribute towards the development of basic building blocks to power the future generation of wearables. In addition, electrophoretic deposition of nanocrystalline cellulose films on enhancing TEGs electrical output was also studied. A quantification of both tribo and piezoelectric phenomenon contribution for the final output was estimated.





When: 2022-06-22, 08:00 - 08:15, Where: Parallel session 1

Surface modified thermoplastic polyurethane and poly(vinylidene fluoride) nanofiber based flexible triboelectric nanogenerator and wearable bio-sensor

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Sk Shamim Hasan Abir[1, 2]
Karen Lozano[2, 3], Mohammed Jasim Uddin[1, 4]
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[4] Department of Chemistry, University of Texas Rio Grande Valley, Edinburg, Texas 78539, United States.

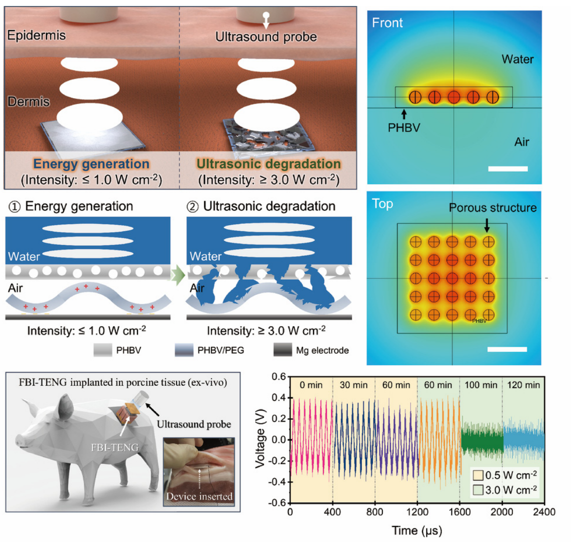
Abstract text: Over the last few years, nanofiber-based triboelectric nanogenerator (TENG) has caught great attention among researchers all over the world due to its inherent capability of converting mechanical energy to usable electrical energy. In this study, poly(vinylidene fluoride) (PVDF) and thermoplastic polyurethane (TPU) nanofiber prepared by Forcespinning® (FS) technique were used to fabricate TENG for self-charging energy storage device and biomechanical body motion sensor. The surface of the TPU nanofiber was modified by uniform deposition of thin gold film to enhance the frictional properties; yielded 254 V open-circuit voltage (V_{oc}) and 86 μA short circuit current (I_{sc}), which were 2.12 and 1.87 times greater in contrast to bare PVDF-TPU TENG. Moreover, the as-fabricated PVDF-TPU/Au TENG was tested against variable capacitors and resistive load and the results showed that with a 3.2 x 2.5 cm^2 active contact area, it can quick charge up to 7.64 V within 30 seconds using a 1.0 μF capacitor and generate significant 2.54 mW power, enough to light 75 commercial LEDs (1.5 V each) by the hand tapping motion at 4 Hz (240 beats per minutes (bpm)) load frequency. Furthermore, the TENG was attached to different body parts to capture distinctive electrical signals for various body movements elucidated the prospective usability of our prepared nanofiber-based TENG in wearable body motion sensor application.

Ultrasound-triggered triboelectric nanogenerator for powering on-demand transient electronics

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Dong-Min Lee[1]
Sang-Woo Kim[1]
[1] Sungkyunkwan University (SKKU)

Abstract text: On-demand transient electronics, technologies referring subsequent material disintegration under well-defined triggering events and programmed timelines, offer exceptional clinical experiences in diagnosis, treatment, and rehabilitation. Despite potential benefits, such as the elimination of surgical device removal and reduction of long-term inimical effects, their use is limited by the non-transient conventional power supplies. Here, we report an ultrasound-mediated transient triboelectric nanogenerator (TENG) where ultrasound determines energy generation and degradation period. Our findings on finite element method simulation show that porous structures of the poly(3-hydroxybutyrate-co-3-hydroxyvalerate) play an essential role in the triggering transient process of our device under high-intensity ultrasound. We successfully demonstrate the tunable transient performances by ex-vivo experiment using a porcine tissue. This study provides insight into practical use of implantable TENGs based on ultrasound-triggered transient material design.



When: 2022-06-20, 12:25 - 12:50, Where: Parallel session 3

Environment-adaptive Triboelectric Nanogenerators for Wearables

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Jiaqing Xiong[1]

[1] Donghua University

Abstract text: Human-machine-environment interactions rely on soft intelligent bio-interface between organisms and objects as well as the surrounding environment. Materials/devices with superiorities in mechanics, wettability, electrics, and optoelectronics promise to bridge the technology gap, building breathable interfaces with dynamic responsibility, bioaffinity, biocompatibility and intelligent functions for immersive interactions. Triboelectric nanogenerator (TENG) is an emerging low-cost technology for distributed energy harvesting and self-powered sensing. Materials innovation to realize function responsibility and environment self-adaptivity on TENGs is important for the development of wearable/attachable self-powered devices for interface applications, such as sensing, perception, augmented virtuality, health monitoring, disease detection, and intervention therapy. To realize adaptive device to diverse environment around, we developed a series of TENGs based on elastomers and elastic textiles, embodying the transition of TENGs from attachable to wearable as well as e-skins and on-spot devices. A sticky porous elastomer encapsulated with gas was proposed for a gas-solid interacted TENG as self-attachable sensor for health monitoring. Innovative hydrophobic nanocellulose was developed to enrich functions of multi-substrates such as electronic-paper, elastomers, fibers and textiles, together with versatile strategies to improve the mechanical, optical and interface properties of TENGs, extending the application scenarios with diversity in deformation stimulus, temperature, humidity, water, corrosions and wind. Our works would promote the awareness to develop more advanced materials with adaptivity and sustainability, inspire more considerations on the performance balance of TENGs to expand the application scope.

When: 2022-06-21, 13:45 - 14:10, Where: Parallel session 1

Omnidirectional textile-based triboelectric energy harvesting for wearable applications

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Steve Beeby[1]
Watcharapong Paosangthong[1]
[1] Centre for Flexible Electronics and E-Textiles, School of Electronics and Computer Science, University of Southampton

Abstract text: Powering electronic textile systems (e-textiles) is an ongoing challenge since the current reliance on traditional batteries is incompatible with the properties and feel of a fabric. We have investigated textile-based triboelectric nanogenerator (TENG) with alternate strips of positive and negative triboelectric materials designed to operate in the freestanding triboelectric-layer mode. This initial device, defined as a pnG-TENG, demonstrated the benefits of using both positive and negative materials in the generator structure and achieved a maximum root mean square (RMS) power density of 38.8 mW/m^2, which is 1.9 and 6.4 times larger than a TENG based upon a single triboelectric material and a TENG with no gratings, respectively. However, the pnG-TENG only operated from movement in a single direction. A new textile TENG design is presented comprising woven strips of positive and negative triboelectric material which form a checkered pattern. This has a matching periodicity with a textile based woven electrode layer and this arrangement allows the woven-TENG to harvest mechanical energy from all movement directions in the plane of the device. Again, the use of both positive and negative triboelectric materials significantly improves harvester performance and the woven-TENG comprising strips of nylon and polytetrafluoroethylenevinyl (PTFE) fabric can generate an RMS open-circuit voltage of 62.9 V, RMS short-circuit current of 1.77 μA and a maximum RMS power of 34.8 μW across a load resistance of 50 MΩ from a mechanical oscillation of 2 Hz, a contact force of 5 N corresponding to a maximum RMS power density of 5.43 mW/m^2.

When: 2022-06-21, 12:00 - 12:25, Where: Parallel session 1

Tribotronics: an Emerging Field by Coupling Triboelectricity and Semiconductor

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Chi Zhang[1]
[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences

Abstract text: Tribotronics has attracted great attentions as an emerging research field by coupling triboelectricity and semiconductor. On the one hand, the research is about the electronics of interfacial friction. The energy conversion mechanism of DC power generation by the semiconductor interface friction has been revealed, the tribovoltaic effect has been proposed, and the high power density triboelectric devices have been realized. The modulating characteristics on transistor by contact electrification have been revealed, a series of tribotronic functional devices have been developed, and the nanoscale triboelectrification gated transistor has been realized. On the other hand, the research is about the triboelectricity based on electronics theory and technology. The advantages of triboelectric nanogenerator for low frequency and weak mechanical energy conversion are revealed, and the triboelectric MEMS actuated by ultralow frequency mechanical stimuli have been developed. A universal power management strategy based on transistor switch for triboelectric nanogenerator is proposed, various triboelectric self-powered microsystems are realized, and the application for wireless sensor nodes in industrial field is demonstrated. By the research prospects for interactions between triboelectricity and semiconductor, tribotronics is expected for significant impacts and potential applications in MEMS/NEMS, flexible electronics, robotics, wireless sensor network, and Internet of Things.

When: 2022-06-21, 12:25 - 12:50, Where: Parallel session 1

Ultimate output and energy management of triboelectric nanogenerator

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Chenguo Hu[1]

[1] Department of Applied Physics, Chongqing University, Chongqing, 400044, P. R. China.

Abstract text: Triboelectric nanogenerator (TENG) is one of the most important technologies to solve the problem of distributed energy supply of wireless sensor networks. However, the low output performance and the high output impedance of TENG limit its practical application. Poor contact with the tribo-material interface, air breakdown effect, and insufficient charge generation capability are the main factors affecting TENG charge density. The impedance mismatch between TENG and target electric devices results in low energy utilization. In this talk, I will introduce the works for boosting output performance and energy management of TENG in our group, including the charge excitation strategy, material modification, structure design, specifically, the criteria for quantitative evaluation of the contact status for contact-separation TENG, and the enhancement of charge generation capacity by shielding layer and device structural design of the sliding TENG. At the same time, I will talk about our proposed methods for TENG energy management, such as switching capacitance method for fractal design, automatic Spark switch, and method combined with parameter matching transformer and inductor.

References

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When: 2022-06-20, 12:50 - 13:05, Where: Parallel session 2

A Bioresorbable Dynamic Pressure Sensor for Cardiovascular Postoperative Care

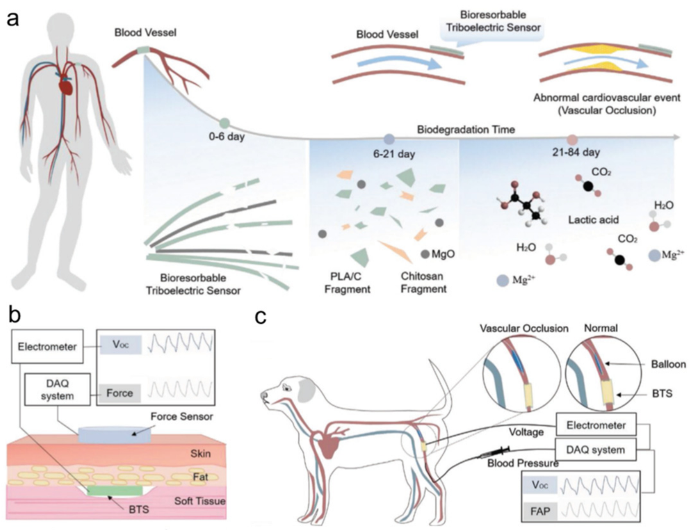
1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

Zhe Li[1]

[1] Beijing Institute of Technology

Abstract text: Bioresorbable electronics that can be absorbed and become part of the organism after their service life are a new trend to avoid secondary invasive surgery. However, the material limitation is a significant challenge. There are fewer biodegradable materials with pressure-sensitive properties. Here, a pressure sensor based on the triboelectric effect between bioabsorbable materials is reported. This effect is available in almost all materials. The bioresorbable triboelectric sensor (BTS) can directly convert ambient pressure changes into electrical signals. This device successfully identifies abnormal vascular occlusion events in large animals (dogs). The service life of the BTS reaches 5 days with a high service efficiency (5.95%). The BTS offers excellent sensitivity (11 mV mmHg^{-1}), linearity ($R^2 = 0.993$), and good durability (450 000 cycles). The antibacterial bioresorbable materials (poly(lactic acid)–(chitosan 4%)) for the BTS can achieve 99% sterilization. Triboelectric devices are expected to be applied in postoperative care as bioresorbable electronics.



When: 2022-06-20, 13:05 - 13:20, Where: Parallel session 2

A paper based human-machine interface: Towards fully green and recyclable Internet of Things

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Jesper Edberg[1, 2]
Ulrika Linderhed[1, 3], Yusuf Mulla[1, 2], Robert Brooke[1, 2], Sandra Pantzare[1], Jan Strandberg[1], Andreas Fall[2, 4], Konstantin Economou[5], Valerio Beni[1, 2], Astrid Armgarth[1]
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[4] RISE Research Institutes of Sweden, Bioeconomy, Drottning Kristinas väg 61, SE-114 28, Stockholm, Sweden.
[5] Linköping University, Department of Culture and Society, Division of Culture, Society, Design and Media (KSFM), Norrköping SE-601 74, Sweden.

Abstract text: The transition to a sustainable society is driving the development of green electronic solutions which are designed to have a minimal environmental impact. One promising route to achieve this goal is to construct electronics from biobased materials like cellulose which is carbon neutral, non-toxic, and which can be recycled. This is especially true for IoT devices which are rapidly growing in number and are becoming embedded in every aspect of our lives. Here, we demonstrate a paper-based electronic "book" which uses triboelectric pressure sensors to help elderly people communicate with the digital world using an interface which is more intuitive to them. The sensors were manufactured by screen printing onto flexible paper substrates, using in-house developed cellulose-based inks with non-hazardous solvents. The triboelectric sensor signal, generated by the contact between a finger and chemically modified cellulose, could reach several volts which could be registered by a portable microcontroller card and transmitted by Bluetooth to any device with an internet connection. Apart from the MCU card (which can be easily removed), the whole system can be put in paper recycling at end of life.

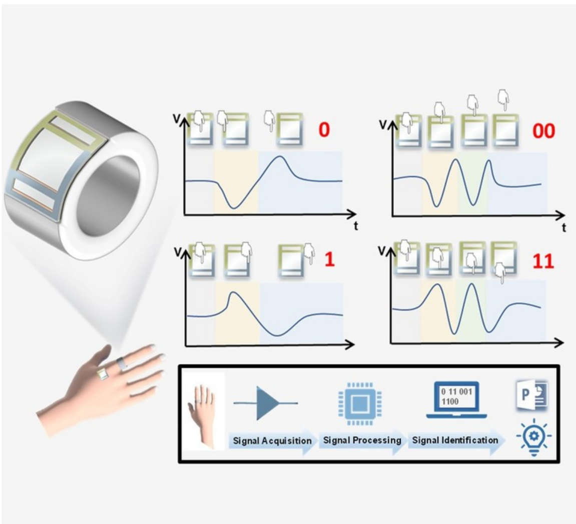
When: 2022-06-21, 08:50 - 09:05, Where: Parallel session 2

A single-channel and patterned triboelectric sensor for multipurpose human-machine interface

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Zhiping Feng[1]
Jin Yang*[1]
[1] College of optoelectronic engineering, Chongqing University

Abstract text: Triboelectric interfaces have already been extensively researched in human-machine interaction owing to their self-sustainability, low cost, easy manufacturing, and diverse configurations. However, some limitations (*e.g.*, many electrodes, multiple lines, and chunks) hinder the further development of human-machine interaction applications. Herein, a triboelectric encoding interface is proposed by designing the reverse polarity of the tribo-layers to encode the voltage signals. Owing to the inversion of the tribo-layers and the number of electrodes, this encoding method can realize multipurpose commands by using fewer electrodes and one triboelectric device with simple structure, which greatly reduces the size of the device and the influence of uneven force. The triboelectric sensor with nano-structure has good sensitivity (1.55 V/N) and durability (> 30000 cycles). Moreover, a ring with the patterned interface (150 mm × 200 mm) was demonstrated to achieve slide presentation and electric appliance control, which contributes to more design strategies for intelligent control.



When: 2022-06-20, 14:35 - 15:00, Where: Parallel session 2

An anemograph inspired triboelectric nanogenerator for contaminative and high temperature exhaust gas flow monitoring on ships

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

Fangyang Dong[1, 2]

Taili Du[1, 2], Meixian Zhu[2], Ziyue Xi[1], Yongjiu Zou[1, 2], Peiting Sun[2], **Minyi Xu**[1]

[1] Dalian Key Lab of Marine Micro/Nano Energy and Self-powered Systems, Marine Engineering College, Dalian Maritime University, Dalian, 116026, China

[2] Collaborative Innovation Research Institute of Autonomous Ship, Dalian Maritime University, Dalian 116026, China

Abstract text: Measuring the exhaust gas flow is of great significance to ensure the implementation of the NOx emission reduction measures on ships in the era of green ship. It is essential to develop an accurate and online self-powered flow sensor for monitoring the exhaust gas flow timely due to the harsh working environment with particulate matters and high temperature. In this work, an anemograph inspired triboelectric nanogenerator (AN-TENG) sensor for contaminative and high temperature exhaust gas flow monitoring on ships is proposed and systematically studied. The AN-TENG sensor consists of rotating cup, steel balls, polytetrafluoroethylene (PTFE) film, copper electrodes and 3D-printed container. The design of the AN-TENG allows steel balls to roll on PTFE film driven by the gas flow, leading to periodical electrical signals on the two copper electrodes, which realizes the flow sensing. The peak voltage reaches 106 V when the velocity of the gas flow is 14 m/s. The test results show that the open-circuit voltage and the fast Fourier transform result of voltage signal agrees well with the gas flow range of 2.5 to 14m/s, which meet the requirements of the gas flow range in 25-100% engine power. The linear correlation coefficient of them achieve 0.9896 and 0.9988 respectively. The output performance of the AN-TENG under different particulate matter concentration of 0-120 mg/Nm^3 and temperature of 50-180 °C are also investigated with hardly any flow sensing performance deterioration. Therefore, the present AN- TENG has a great potential to apply for exhaust gas flow monitoring on ships.

When: 2022-06-20, 14:35 - 15:00, Where: Parallel session 3

Enhanced Streaming Vibration Potential by Silane-Modificated MXene/PVA Hydrogel for High-Performance Flexible Triboelectric Nanogenerator

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Triboelectric nanogenerators (TENGs) play a vital role in self-powered electronics, based on their superior energy harvesting ability and simple construction. In this work, polyvinyl alcohol (PVA) hydrogel is fabricated, exhibiting a three-dimensional (3D) network structure that allows PVA chains to be covered by a large amount of water. Combining MXene nanosheets with the hydrogel TENG, the composite improves the ion transport of the hydrogel and provides the streaming vibration potential (SVP) mechanism. This composite effectively enhances the output performance of hydrogel TENG. Furthermore, this work adopts different functional groups of silane (APTES, CPTMS, FOTS) to modify the surface work function of MXene nanosheets. The surface modification increases the charge density at the interface between MXene and water inside the hydrogel, improving the electrical output performance and mechanical sensitivity of MXene hydrogel TENG (MH-TENG). The result demonstrates that the electrical output performance of MH-TENGs modified by 1H,1H,2H,2H-Perfluorooctyltriethoxysilane (FOTS) is approximately two times larger (output-voltage~85 V/output-current~240 nA) than pristine hydrogel TENG (output-voltage~40 V/output-current~100 nA). The MH-TENG behaves unlimited potential in the use of flexible electronics, such as movement monitoring electronics, strength sensors on the paddle, and wearable energy harvesting devices in the future.

Key words: triboelectric nanogenerator, silane, streaming vibration potential, hydrogel

When: 2022-06-21, 09:05 - 09:20, Where: Parallel session 3

High-Performance Triboelectric Lignin Films for Self-Powered Wearables Devices

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: Lignin is a complex biopolymer that keeps the structural integrity of plants. This naturally abundant material is a potential renewable resource that is nowadays part of the transforming forest and agricultural feedstock towards a more sustainable resources management. However, with a dominant aromatic structure, lignin hinders its processability under non-organic solvents. Herein, we manufactured lignin films though blade-coating by implementing a new environmentally friendly processing method. In order to obtain a processable viscous ink and thin films, we mixed lignin with other biopolymers and evaluated their sensing performance. Lignin containing films were fabricated by distinct manufacture parameters and the sensing performance was evaluated. The optimal parameters of manufactured lignin films were compared to pure biopolymer films, showing outstanding triboelectric properties. Moreover, we assessed the performance of the films as self-powered wearable devices in a human-machine interface application. This environmentally friendly processing method promotes the revalorization of lignin as a renewable material for wearable devices.

When: 2022-06-21, 09:05 - 09:20, Where: Parallel session 2

Hybrid PDMS-TiO2-stainless steel textiles for triboelectric nanogenerators and appications in infrared rays wireless communication

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Electrophoretic deposition is employed to deposit flower-like TiO_2 (F-TiO_2) particles onto stainless steel textiles to obtain a Fe@F-TiO_2/PDMS hybrid textile as the negative tribo-material. The electrophoresis process enables adjustable deposit amounts and three-dimensional and uniform deposits of flower TiO_2. The textile triboelectric
nanogenerators (tTENGs) fabricated from the Fe@F-TiO_2/PDMS hybrid textile working in conjunction with cotton and silk exhibit excellent performances. The tTENG generates a voltage of 120 V, a current of 25 μA and an output power of 0.85 W/m 2 with the cotton and 110 V, 30 μA and 1.05 W/m2 with the silk. The flower-like TiO_2 is significant for the high performance of the tTENG, being attributed to the tailored surface and improved
permittivity. Wearable tTENGs exhibit good durability after 8,000 cycles and power 58 light emitting diodes. By utilizing the worn tTENG, real-time biomechanical energy harvesting is realized; furthermore, a wireless communication via infrared rays is achieved, confirmed by the successfully receiving of the wireless signal and lighting up of the indicator LED. This work demonstrates high-performance hybrid textiles prepared by electrophoretic deposition and tTENGs for applications in wearable real-time energy harvesters and wireless communication units.

When: 2022-06-21, 08:50 - 09:05, Where: Parallel session 3

Machine learning triboelectric textile system for multimodal objects identification

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: Smart wearables with self-sensing capabilities, such as tactile sensing, play an important role in environment awareness and interaction. The integration of machine learning technique can undermine more information from tactile signals, which could render tactile sensing the capability for multimodal sensing of objects. Such multimodal sensing capabilities could enable traditional sensing system to perceive objects details in more harsh environments, like dark or non-visible environments. Here, a smart glove-wristband system is presented to recognize materials and shapes of different objects. Textile triboelectric nanogenerator (TENG) sensors were built on the wristband to collect motion signals related to objects shapes, and TENG tactile sensors were integrated on the glove to detect material information of objects. Soft tactile sensors enable capturing rich information from objects, and higher-level features could be extracted by leveraging machine learning algorithms. The smart glove-wristband system demonstrates the ability to identify materials and shapes of 10 objects with high accuracy. The machine learning glove-wristband triboelectric textile system may be promising for multimodal human-machine interface in smart home/industry applications, especially for remote multimodal sensing in non-visible environments.

When: 2022-06-21, 10:25 - 10:40, Where: Parallel session 2

Scalable production of functional dielectric layers for tribo-electric nanogenerator sensors

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: This work is an early-stage evaluation of mass production potential for tribo-electric nano generator (TENG) sensors. The aim is to evaluate a simple, cost effective screen printing process with a positive photoresist stencil to produce functional dielectric layers for TENG sensors on a temporary substrate. Screen printing uses a fine mesh of fabric that allows ink deposition on a substrate. A photo emulsion gel and photosensitive inkjet paper is used to create a positive photoresist stencil, allowing the dielectric layer to be manufactured without post process cutting. This process is evaluated on four facets: precision, repeatability, scalability and economic viability. Precision refers to controllability of layer thickness, of shape and of dimensions of the pattern. Repeatability refers to the number of production cycles before reduction in precision. Allowing the evaluation of the longevity of the process when moving towards mass production. Scalability refers to the increase in production output towards mass production for industrial applications while maintaining precision and repeatability. Finally, economic viability refers to the ability of maintaining cost effectiveness throughout the process of scaling for mass production. This method uses a temporary substrate that allows the dielectric material to easily peel off, a secondary pick and place process is used. Exploiting the viscoelastic properties of PDMS to transfer the dielectric layer on the structural base and electrode of the TENG sensor. This research is valuable as it helps establish the fundamental building blocks for mass production of functional dielectric layers used to manufacture TENG devices during commercialization efforts.

When: 2022-06-21, 10:40 - 10:55, Where: Parallel session 2

Smart ping pong paddle of triboelectric self-powered wireless sensors based on surface functionalization of polydimethylsiloxane film

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Triboelectric nanogenerator (TENG) has considerable application potential in mechanical force sensing. Its self-powered feature facilitates the design of the sensing system and requires no battery installation. We utilize 1H, 1H, 2H, 2Hperfluorooctyltriethoxysilane (FOTS) to modulate the work function, surface potential, and electronegativity of the polydimethylsiloxane (PDMS). The output voltage and current of the PDMS-FOTS TENG reached 175 V and 0.1μA, respectively, which is 40-fold and 200-fold higher than pristine polyurethane (PU) TENG. The PDMS-FOTS TENG is integrated with data acquisition (DAQ), BlueTooth device, and humanmachine interface to fabricate a wireless ping pong paddle. Through the creation of the database and the algorithm's design, the sensors' electrical signal can be analyzed with the ball's momentum, position, and force. The cycle test confirms the wireless analysis system of the smart ping pong paddle that possesses excellent sensing stability and sensitivity, which can reach 100 % accurate sensing point differentiation. In response to the high-speed movement of the sphere, the sensing performance results have successfully achieved a sampling frequency of up to 10,000 Hz and an error range of less than 5%. This work successfully developed a wireless system and also opened up application directions for TENGs. Key words ： triboelectric nanogenerator, self-powered wireless sensor, surface functionalization, smart paddle

When: 2022-06-21, 12:50 - 13:05, Where: Parallel session 2

Smart textile triboelectric nanogenerators

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: As a new kind of smart textile technology, textile triboelectric nanogenerator (TENG) can seamlessly integrate traditional wearable textile materials with advanced TENG science, which not only embraces the abilities of energy autonomy supply and self-powered sensing, but also maintains the desired aesthetic perception and comfortability for wearing. With the advantages of lightweight, low cost, flexible structure, extensive material selections, and high performance at low operating frequencies, textile TENGs have received broad interests both from research and industry fields, which show great application prospects in wearable micro-/nano power sources, self-powered sensing, healthcare monitoring, biomimetic systems, human-machine interfaces, and artificial intelligence. However, two key bottlenecks, i.e., low output power and inferior sensing ability have largely limited the development of textile TENGs. Large numbers of efforts have been made in order to improve the performance of the two aspects. This report aims to summarize these methods, which can provide theoretical guidance for the design and application development of textile TENGs in the future.

When: 2022-06-21, 13:05 - 13:20, Where: Parallel session 2

Triboelectric Nanogenerator for Car Detection using RF Transmission Based on a Plasma Switch

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Two road bumps with a movable upper plate have been fabricated so that a transducer with a surface of up to 625 cm^2 can be excited with a vertical deflection. The electromechanical energy conversion is achieved by combining the contact between 2 suitable triboelectric materials with a significant variation of the transducer capacitance. The transducer is made of a PTFE sheet of 25x23 cm^2 wide and 100 µm thick glued with double-sided adhesive tape on one electrode, and a second contact electrode made of aluminum. For the preliminary tests described in this abstract, softer springs were used so that vertical deflection could be achieved by a human step.

Up to 200 µJ were obtained from scratch with a single human step. Considering that a car is much heavier and would generates 4 actuations, the energy harvested in a real situation should be at least one order of magnitude higher. Each actuation of the triboelectric transducer can generate a voltage up to 1 kV. We used this high-voltage to generate a sparkle based on a micro-plasma switch that induces an electromagnetic wave [1]. Up to 3 meters, a short oscillation was detected by the receiver. The amplitude of the received signal gives an indication of the force applied on the transducer.

This approach is promising since almost no electronic is needed to transmit the information. Much higher power is expected with a car, thus the transmission distance can be extended and can maximize the harvested energy for a self-powered system.

doi:10.1126/sciadv.abi6751

When: 2022-06-22, 09:30 - 09:45, Where: Parallel session 2

Triboelectrification induced self-powered microbial disinfection using nanowire-enhanced electric field

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Air-transmitted pathogens may lead to severe epidemics (e.g., COVID-19) showing huge threats to public health. Inactivation of the pathogenic microbes in the air is an essential process, whereas the feasibility of existing air disinfection technologies has encountered obstacles including only achieving physical separation but no inactivation, obvious pressure drops, and energy intensiveness. Here we report a rapid disinfection method for inactivating air-transmitted bacteria and viruses using the nanowire-enhanced localized electric field to damage the outer structures of microbes.[1] This air disinfection system is driven by a triboelectric nanogenerator that converts mechanical vibration to electricity effectively and achieves self-powered. Assisted by a rational design for the accelerated charging and trapping of microbes, this self-powered air disinfection system promotes the microbial transport and achieves high performance: >99.99% microbial inactivation within 0.025s in a fast airflow (2 m/s) while only causing low pressure drops (<24 Pa). This rapid, self-powered air disinfection method may fill the urgent need for the air-transmitted microbial inactivation to protect public health.

Ultrasound-driven triboelectric nanogenerator with implantable, modulus tunable hydrogel

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: In this study, we suggested an implantable, modulus-tunable ultrasound-driven triboelectric nanogenerator (IMU-TENG) based on a multi-functional, biocompatible 2-hydroxyethyl methacrylate (HEMA) hydrogel. Firstly, by engineering the acoustic impedance of HEMA with varying crosslinking concentrations, which is highly related to the elastic modulus, the ultrasonic transmission to the device was increased by 41.5 %. Secondly, the triboelectric property of HEMA was enhanced by adding an ionic monomer, resulting in an increased triboelectric output performance. Subsequently, IMU-TENG could charge a 100 μF capacitor under in vivo condition at a rate of 23.9 μC/s, which was 3.7 times faster than the case with titanium plate. This strategy of using HEMA with tunable acoustic impedance and triboelectric property as both encapsulation and triboelectric layer, can highly enhance the output performance of ultrasound-driven TENG for battery charging of medical implants.

When: 2022-06-21, 14:35 - 14:50, Where: Parallel session 2

Using solid-liquid triboelectric nanogenerator for coating wear condition monitoring

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: Due to wear, functional coatings degrade continuously in service environment resulting in the loss of the protective effect on the substrate. Unprotected workpieces in harsh conditions will rapidly reduce their service life and have high property and safety risks while wear monitoring help to prevent the risks. Therefore, it is of great significance to monitor the wear of coating during application, especially an *in-situ* method that can monitor the wear of coating in real time. As an emerging technology, triboelectric nanogenerator (TENG) can transfer the mechanical energy into electricity and has good response to coating properties, which makes it possible to monitor coating conditions. In this study, a solid-liquid TENG is developed based on lignin-based polyurethane coating. It is found that the developed TENG can generate a corresponding electric signal with different wear states, which can be used to evaluate the coating degradation conditions. It is believed that the increased surface roughness caused by wear and the penetrated water into the coating are the main reasons affect the TENG signal output for this polymer coating. The real-time output signal is generated by the coating-water contact separation motion, which directly reflects the degradation of coating performance without any additional equipment. This study provides a potential new scheme for the *in-situ* coating monitoring.

When: 2022-06-22, 10:25 - 10:40, Where: Parallel session 1

Using triboelectric nano-generator for high-frequency vibration monitoring

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Triboelectricity is the phenomenon of generating surface contact electrification (when two dissimilar material brought in physical contact) and electrostatic induction (electron flow due to potential drop when the charged surface separate). A triboelectric nanogenerator (TENG) utilizes a triboelectricity mechanism to convert mechanical energy into electrical energy, and the performance is significantly influenced by the mode of operation, material properties, and surface contact area. Promising results have been achieved by improving the performance of TENG-based vibration energy harvesters by modifying these parameters. However, their function is limited to low frequencies. This work presents an optimized TENG-based vibration energy harvester for higher frequencies and a broad range of frequencies through structural design supported by numerical simulations. Two alternative structures are developed. One spring-assisted, and one freestanding ball in plate design, with the aim to study the effect of
structural design on TENG output. The experimental results show that the developed TENG based samples can successfully harvest vibration energy within the frequency range of 0-1200Hz. Due to the optimized structural symmetry, larger surface contact area, and effective spring stiffness, the two spring-assisted (TS) structures generate higher electric signal output (up to 200V and 0.9μA). The application of developed TENG extended for TENG-based vibration sensor to monitor machine condition. The sensors generate uniform and stable signals when compared to the commercial vibration sensor and demonstrate promising potential to detect bearing defect.

When: 2022-06-22, 09:15 - 09:30, Where: Parallel session 2

Virus blocking textile for SARS-CoV-2 powered by human body triboelectric energy harvesting

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Effective mitigation technology to prevent the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is required before achieving population immunity through vaccines. Here we demonstrate a virus blocking textile (VBT) which repulses SARS-CoV-2 by applying repulsive Coulomb force to respiratory particles, powered by human body triboelectric energy harvesting. We found that SARS-CoV-2 has negative charges and a human body generates high output current of which peak-to-peak value reaches to 259.6 μA at most, based on triboelectric effect. Thereby, the human body can sustainably power a VBT to have negative electrical potential and the VBT highly blocks SARS-CoV-2 by repulsing them. In acrylic chamber study, we found that the VBT blocks SARS-CoV-2 by 99.95 % and SARS-CoV-2 in the VBT is 13-times reduced. Our work provides the first technology that prevents the spread of virus based on repulsive Coulomb force and triboelectric energy harvesting.

When: 2022-06-20, 12:00 - 12:25, Where: Parallel session 2

A TENG-based Neuromorphic tactile Sensor System

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Current electronic (e-) skins comprise tactile sensor arrays, each sensor of which is sampled serially using conventional readout circuits. They suffer generally from an increased stimulation-to-readout latency and increased power consumption with an increase in the number of sensors, thus limiting the scalability of the e-skin required for practical applications. Unlike the natural skins in which tactile information is powerfully processed in the peripheral nervous system before reaching the central nervous system, the conventional e-skins lack the capability of signal processing. Here we present a biomimetic e-skin that is self-powered in sensing and is proficient in neural signaling. Our neuromorphic e-skin is composed of a tactile sensor array based on the triboelectric nanogenerator (TENG) technology and a neuromorphic circuit. The former receives mechanical stimulation and converts the stimulus into an analog voltage, mimicking the tactile mechanoreceptors. The analog voltage is subsequently converted into electric pulses (spikes) via the circuit with either a ring oscillator [1] or an analog circuit following the leaky integrate-and-fire model neuron. When we included a synaptic circuit subsequently, the operation of the hardware is well described by a convolutional neural network. The system is event-driven, of low power consumption during active operations and parallel in signal transmission and processing. Furthermore, the biomimetic signaling offered by the system allows for multiple coding mechanisms to work simultaneously which is beneficial to reach human-like tactile perception.

[1] Chen, L., etc., Artificial tactile peripheral nervous system supported by self-powered transducers, Nano Energy 82, 105680, 2021

When: 2022-06-20, 12:25 - 12:50, Where: Parallel session 2

Advances in Self-Powered Triboelectric Pressure Sensors

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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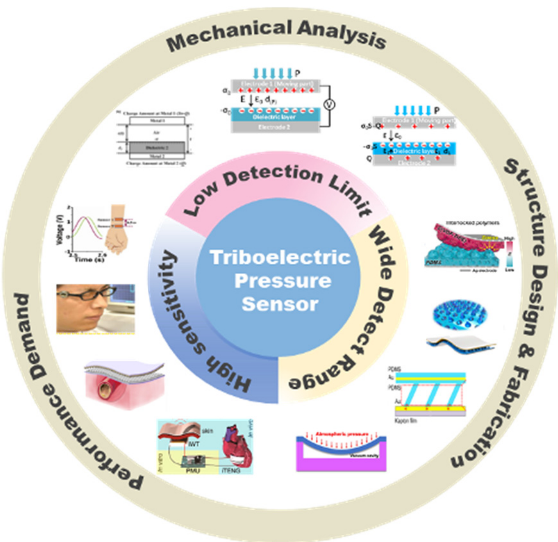
Abstract text: Pressure sensors have attracted much attention for their potential applications in health monitoring, wearable devices, electronic skin and smart robots, etc. With the rapid development of Internet of things, considering the large number and small scale of sensors, power consumption also plays a key role in their large-scale applications. A new generation of self-powered pressure sensor based on triboelectric nanogenerator has been developed in terms of its incomparable advantages in power consumption and potential performance. Based on the coupling effects of triboelectrification and electrostatic induction, it enables to obtain the information on the mechanical input, e.g., magnitude and frequency, by analyzing electrical output signals. Intensive efforts have been devoted to improve the sensing performance of triboelectric pressure sensor to meet the demand of the practicality. In this talk, the key advancements in materials, structures and applications of self-powered triboelectric pressure sensors will be systematically introduced. Then, the theoretical basis, impact mechanism and the approaches to optimize the pressure sensing performance will be comprehensively analyzed. Afterwards, I will summarize the typical applications of triboelectric pressure sensors in different pressure ranges and working frequencies. Finally, the future perspectives of self-powered triboelectric pressure sensor will also be discussed.



When: 2022-06-22, 10:40 - 10:55, Where: Parallel session 1

Wearable and energy autonomous biosensors for healthcare: proof of concept graphene-based pH sensor

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Fast detection of biomarkers is one of the pillars of medical diagnosis, and a major driving force for the health industry. In the frame of the Wearable Applications enabled by electronic Systems on Paper (WASP) project, we develop wearable sensors, based on graphene inks. Carbon-based electrochemical sensors are widely developed because of their low cost and biocompatibility. In terms of sensitivity, graphene-based sensors present a large electroactive surface area and good electron transfer kinetics. In this work we present the pH sensing capabilities of flexible graphene ink-based devices, for their use in (e.g.) disposable smart band-aids to monitor bound infection. We will present the sensitivity to pH of our flexible device under different detection electrochemical approaches.

Such wearable devices are an emerging technology that has the healthcare space as one of its most promising markets. The development of Internet of Things (IoT) ecosystems will boost the number of our day life point-of-care electronics, which is set to triple to 25 billion by 2030. Thus, the environmental impact and health hazards of powering all these devices by conventional batteries are impractical and finding new energy technologies for truly self-powered systems is one of the main challenges of our civilization. In this work, we will also explore the direct coupling of a triboelectric energy generator with our wearable sensor technology to detect pH changes in the environment, in the range of 4-7, where the pH shift of an infection is observed.

When: 2022-06-20, 13:45 - 14:10, Where: Parallel session 2

Advances in Triboelectric Human-Machine-Interfaces

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: Entering the 5G and internet of things (IoT) era, human–machine interfaces (HMIs) capable of providing humans with more intuitive interaction with the digitalized world have experienced a flourishing development in the past few years. Although the advanced sensing techniques based on complementary metal-oxide-semiconductor (CMOS) or microelectromechanical system (MEMS) solutions, e.g., camera, microphone, inertial measurement unit (IMU), etc., and flexible solutions, e.g., stretchable conductor, optical fiber, etc., have been widely utilized as sensing components for wearable/non-wearable HMIs development, the relatively high-power consumption of these sensors remains a concern, especially for wearable/portable scenarios. Recent progress on triboelectric nanogenerator (TENG) self-powered sensors provides a new possibility for realizing low-power/self-sustainable HMIs by directly converting biomechanical energies into valuable sensory information. Leveraging the advantages of wide material choices and diversified structural design, TENGs have been successfully developed into various forms of HMIs, including glove, glasses, touchpad, exoskeleton, electronic skin, etc., for sundry applications, e.g., collaborative operation, personal healthcare, robot perception, smart home, etc. With the evolving artificial intelligence (AI) and haptic feedback technologies, more advanced HMIs could be realized towards intelligent and immersive human–machine interactions. Hence, in this review, we systematically introduce the current TENG HMIs in the aspects of different application scenarios, i.e., wearable, robot-related and smart home, and prospective future development enabled by the AI/haptic-feedback technology. Discussion on implementing self-sustainable/zero-power/passive HMIs in this 5G/IoT era and our perspectives are also provided.

When: 2022-06-20, 14:10 - 14:35, Where: Parallel session 2

Electroactive biomaterials and self-driven systems for biomedical applications

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: Wearable electronic devices have been attracting numerous attention in tactile sensing, motion detection, and biomedical signal monitoring. Thereinto, flexible and self-powered electronics, driven by human body motion without external power supply would have broad applications not only in tactile sensing, but also in disease diagnosis therapy. Our research motivation is to design flexible, wearable, and biocompatible nanomaterials and nanodevices, and apply them in drug delivery and disease therapy. For wearable medicine, we used the self-powered and wearable triboelectric nanogenerator (TENG) as a self-powered electricity source to stimulate stem cells grown on nanostructured electrode, and realized a neural differentiation of the stem cells. Wireless electrical stimulation was also realized via designing the piezoelectric nanomaterials to response to cell movement and traction, which further acted on the cells to modulate cell differentiation. Furthermore, we developed new method for drug delivery into cells and tissues with the self-powered TENG, for potential on-demand and personalized therapy. These studies pave new applications for self-powered nanogenerator and piezoelectric nanomaterials, and alternative way for smart therapy.

When: 2022-06-20, 13:45 - 14:10, Where: Parallel session 3

Flexible mechano-to-electrical energy conversion materials and devices

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: The technology of mechano-to-electrical energy conversion had promoted the second industrial revolution in history, and is still now one of the foundations of modern electrical industry. Recently, there are following new demands and impacts to develop new flexible mechano-to-electrical energy conversion devices, due to the booming of flexible electronics or bionic electronics. First, they can harvest low-grade environmental mechanical energy and serve as power sources for electronics; second, they can serve as force-sensitive sensors or interaction devices, as human bodies express information mainly by mechanical motions or vibrations, such as “speaking and writing”. However, traditional mechano-to-electrical energy conversion devices, such as the electromagnetic generator, can hardly achieve flexibility, and their outputs are low at low frequency and low mechanical amplitude. Therefore, we present our progresses on flexible mechano-to-electrical energy conversion devices based on fiber and elastomer materials. We will also introduce the mechano-to-electrical conversion based on dynamic interfaces of dielectric, semiconductor, and electrolyte materials, respectively. Our new progresses on solid polymeric ionic conductors will also be reported.

When: 2022-06-20, 14:10 - 14:35, Where: Parallel session 3

From triboelectric nanogenerators and electronic skins to actively-perceiving soft robots and autonomous flexible applications

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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Abstract text: Deformable and wearable soft devices (including sensors, electronics, and machines) have attracted great interest because they cannot only extend the scope of smart systems but also provide compliant and safer user experience. Toward the soft future, it is necessary to explore new energy technology. In this talk, deformable and mechanically-durable energy-collecting triboelectric nanogenerators will be demonstrated for not only serving as new energy providers but also self-powered sensing uses. First, super-stretchable triboelectric nanogenerators will be presented for generating electricity by contacting with other materials regardless of various extreme deformation required from uses, such as extreme stretching, multiple twists and folds. Particularly, even experiencing severe tearing damages, the device can retain its functionality to act as a power source for other components. Then, we will discuss the use in self-powered and deformable electronic skins that can actively sense proximity, contact, and pressure to external stimuli via self-generating electricity. The perfect integration of the tribo-skins and soft actuators enables soft robots to perform various actively sensing and interactive tasks. Last, a self-healing, highly-transparent, and super-stretchable triboelectric nanogenerator with energy-extracting and activity-sensing abilities will be demonstrated in the use of self-powered electronic skin.

When: 2022-06-21, 12:00 - 12:25, Where: Parallel session 2

Intelligent diagnosis of lubricating oil condition based on triboelectric nanogenerator

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Intelligent monitoring lubricant is essential for the development of smart machines because unexpected and fatal failures of critical dynamic components in the machines happen every day, threatening the life and health of humans. Inspired by the triboelectric nanogenerators (TENGs) work on water, we present a novel and feasible way to prepare a self-powered triboelectric sensor for real-time monitoring of lubricating oils *via* the contact electrification process of oil-solid contact (O-S TENG). Typical intruding contaminants in pure base oils can be successfully monitored. The O-S TENG has very good sensitivity, which even can respectively detect at least 1 mg ml^{-1} debris and 0.01 wt% water contaminants. Furthermore, the real-time monitoring of formulated engine lubricating oil in a real engine oil tank is achieved. Our results show that electron transfer is possible from oil to solid surface during contact electrification. Electrical output characteristic depends on the screen effect from such as wear debris, deposited carbons and age-induced organic molecules in oils. Previous work only qualitatively identified that the output ability of liquid can be improved by leaving less liquid adsorbed on the TENG surface, but the adsorption mass and adsorption speed of liquid and its consequences for the output performance are not studied. We quantitatively study the internal relationship between output ability and adsorbing behavior of lubricating oils by quartz crystal microbalance with dissipation (QCM-D) for liquid-solid contact interfaces. This study provides a real-time, on-line, self-powered strategy for intelligent diagnosis of lubricating oils.

When: 2022-06-21, 08:00 - 08:25, Where: Parallel session 2

Magnetic-controlled 3D Structure and Self-Powered Applications

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Magnetic-controlled 3D Structure and Self-Powered Applications

The field of stretchable electronics has been developed rapidly in recent years due to their potential importance in diverse fields. Although the development of functional materials and flexible microsystems has been significantly advanced over the past decade, the precise control of soft structures remains a major challenge for practical applications of energy harvesting, functional sensing and interaction. Magnetic material is an attractive candidate that enables multifunctional devices with capabilities in both sensing and actuation.

In this talk, we show that magnetic materials with temporary magnetization can also achieve programmable, multimodal locomotion through a set of judiciously engineered 3D designs. Such 3D soft structures can exhibit various tethered locomotion under the precise control of magnetic fields, including local deformation, unidirectional tilting and omnidirectional rotation. Applications will focus on energy harvesting systems, including a 3D piezoelectric device for non-contact conversion of mechanical energy and active motion sensing, as well as a 3D magnetic-controlled solar cell that automatically tracks the light through continuous and accurate rotation. The design strategy and resulting magnetic-controlled 3D soft structures hold great promise not only for enhanced energy harvesting, but also for multimodal sensing, robotic interfaces, and biomedical devices through further encapsulation.

When: 2022-06-22, 08:25 - 08:50, Where: Parallel session 2

A bio-inspired and self-powered triboelectric tactile sensor for underwater vehicle perception

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

Peng Xu[1]

Jianhua Liu[1], Xinyu Wang[1], Siyuan Wang[1], **Minyi Xu**[1]

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Abstract text: Marine mammals relying on tactile perception for hunting are able to achieve a remarkably high prey capture rate without visual or acoustic perception. Similar tactile sensing abilities have not been fully developed in the artificial perceptual systems of underwater vehicles for gathering information about physical objects. Here, a self-powered triboelectric palm-like tactile sensor (TPTS) is designed to build a tactile perceptual system for underwater vehicles. It is enabled by a three-dimensional structure that mimics the leathery, granular texture in the palms of sea otters, whose inner neural architecture provides additional clues indicating the importance of tactile information. Moreover, the spinosum structure arranged along the sensing unit surface increases sensitivity (0.125V/N). With the assistance of palm structure and triboelectric nanogenerator technology, the proposed TPTS has the ability to detect and distinguish normal and shear external load in real time and approximate the external stimulation area, especially not affected by the touch frequency, that is, it can maintain stable performance under high-frequency contact. To highlight this device's applicability and scalability, different functions of the TPTS are demonstrated, including controlling LED lights, detecting the hardness of samples, and performing non-destructive pipeline evaluation. The results show that the TPTS is a promising tool for integration into grippers mounted on underwater vehicles to complete numerous underwater tasks.

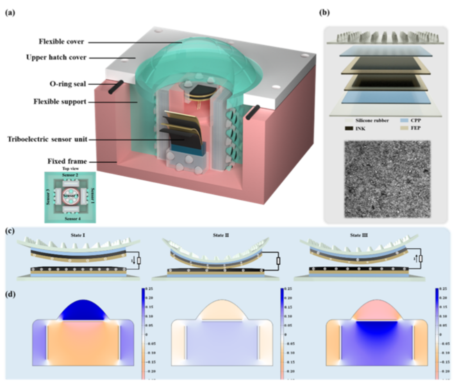

Fig. 1 The structure, working mechanism, and application of TPTS. (a) Structural diagram of TPTS. Inset: top view of the sensor unit layout. (b) Structural diagram of the sensing unit and SEM image of the FEP membrane surface. (c) Charge distribution during contact separation between FEP membrane and conductive ink. (d) Simulation of potential distribution using COMSOL software.

When: 2022-06-21, 08:25 - 08:50, Where: Parallel session 2

Marine self-powered sensors based on triboelectric nanogenerator

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Yongjiu Zou[1]
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Abstract text: With the rapid development of the Internet of Things (IoT) and the ongoing Fourth Industrial Revolution, the innovation of marine sensor network system is regarded as one of the most pivotal technologies for promoting the development of the marine Internet of Things. However, traditional marine sensor energy sources, such as batteries, suffer from pollution problems and limited lifetime when powering widely used marine sensors or electronic devices. Therefore, it is critical to obtain marine self-powered sensors integrated with renewable blue energy source. Triboelectric nanogenerator, based on the coupling effect of contact electrification and electrostatic induction, provides an alternative way for efficiently converting marine mechanical energy to electrical signals, with the advantages of small size, light weight, flexibility and encapsulation In this review article, the latest representative achievements of marine self-powered sensors are comprehensively reviewed, mainly including displacement sensors, flow sensors, velocity sensors and vibration sensors. Finally, an in-depth discussion of the existing challenges and future directions of marine self-powered sensors are clearly presented, which will contribute to the further development of marine self-powered sensor network systems.

When: 2022-06-21, 08:00 - 08:25, Where: Parallel session 3

Mechanical Energy Conversion and Transmission Systems for High-efficient Triboelectric Nanogenerators (TENGs)

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Dukhyun Choi[1]
[1] School of Mechanical Engineering, Sungkyunkwan University

Abstract text: Triboelectric nanogenerators (TENGs) are a promising renewable energy technology. Many applications have been successfully demonstrated, such as self-powered Internet-of-Things sensors and many wearables, and those portable power source devices are useful in daily life due to their light weight, cost effectiveness, and high power conversion. To boost TENG performance, many researchers are working to modulate the surface morphology of the triboelectric layer through surface engineering, surface modification, material selection, etc. Although triboelectric material can obtain a high charge density, achieving high output performance that is predictable and uniform requires mechanical energy conversion systems (MECSs), and their development remains a huge challenge. Many previous works did not provide an MECS or introduced only a simple mechanical system to support the TENG integration system device. However, these kinds of designs cannot boost the output performance or control the output frequency waveform. Currently, some MECS designs use transmission conversion components such as gear-trains, cam-noses, spiral springs, flywheels, or governors that can provide the step-up, controllable, predictable, and uniform output performance required for TENGs to be suitable for daily applications. In this study, we briefly introduce various MECS designs for regulating the output performance of TENGs. First, we provide an overview of simple machines that can be used when designing MECSs and introduce the basic working principles of TENGs. The following sections are MECSs with gear-based, cam-based, flywheel-based, and multiple-stage designs. Last, we present a perspective and outline for a full system design protocol to correlate MECS designs with future TENG applications

When: 2022-06-21, 08:25 - 08:50, Where: Parallel session 3

Novel bidimensional technologies for neural interfaces

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: The discovery of graphene has allowed great advances in implantable medical devices thanks to its outstanding properties which allow to make them smaller, softer, and more conformable. We develop neural interfaces based on graphene for central and peripheral nervous system recording and stimulation, fabricated on flexible and biocompatible substrates and at micrometric size to fulfil implantation purposes.

This medical technology still relies on conventional external batteries, which are connected by wires and usually have a shorter lifetime than the implants themselves. Then, battery replacement must be done frequently, meaning limitations on patient activities, skin infection and additional surgeries, not to mention the discomfort that may cause to have a noticeable disease. Our goal for the future is that implantable medical devices would be powered using long-lasting power suppliers that pose no mechanical or chemical danger to the human body, which do not need to be replaced.

Our neural stimulation technology is based on graphene microelectrodes arrays, which have low power requirements, of microwatt, easy to find in our living environment. With energy harvesting technologies, surrounding energy can be turned into electricity to feed these devices. As a proof-of-concept, I will couple a triboelectric energy generator with a graphene electrode to provide focalized current pulses suitable for local stimulation of the vagus nerve of a small animal model (*e.g.* a rat). The suitability of this approach will open the door to work towards the integration of both components, triboelectric and neural stimulator on a single flexible and biocompatible platform.

When: 2022-06-21, 13:45 - 14:10, Where: Parallel session 2

Scalable nanomanufacturing of biomass based triboelectric wearable sensors

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Wenzhuo Wu[1]
[1] Purdue University

Abstract text: The capability of sensor systems to efficiently scavenge their operational power from stray, weak environmental energies through sustainable pathways could enable viable schemes for self-powered health diagnostics and therapeutics. Triboelectric nanogenerators can effectively transform the otherwise wasted environmental, mechanical energy into electrical power. However, obstacles hindering the development of efficient triboelectric devices based on biocompatible materials continue to prevail. I will discuss our recent progress in the design and engineering of biomass materials for biocompatible, wearable triboelectric devices.

Such wearable devices are conformable to human skins and can sustainably perform non-invasive functions, e.g., gesture recognition and health monitoring, by harvesting the operation power from the human body. The gained fundamental understanding and demonstrated capabilities enable the rational design and holistic engineering of novel materials for more capable biocompatible triboelectric devices that can continuously monitor vital physiological signals for self-powered health diagnostics and therapeutics.

When: 2022-06-21, 10:00 - 10:25, Where: Parallel session 2

Self-Powered Human-Machine Interacting Sensors

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Yanchao Mao[1]
[1] Zhengzhou University

Abstract text: Human-machine interface (HMI) sensor is a technology to transfer and exchange information between human and machine, which has aroused lots of attention recently. We developed a series of self-powered HMI sensors on the basis of triboelectric nanogenerator (TENG). An intelligent wireless respiratory monitoring and alert system was developed by using a TENG based self-powered HMI sensor to real-time alert apnea remotely by using a cell phone to send a warning massage. A smart wireless breath-driven HMI controlling system was developed on the basis of a self-powered sensor. Compared with the conventional interacting methods, this smart system can convert real-time human breathing into command signals to control electronic appliances wirelessly. By utilizing the charges naturally carried on the human body and a TENG, a self-powered touch-free HMI screen sensor is developed for recognizing diverse gestures in a noncontact operating mode. An intelligent noncontact screen control system is further developed, which is used to unlock the smartphone interface by the noncontact operating mode. A thermoregulating and self-powered E-skin based on liquid metal as a phase change material with its melting point in the comfortable temperature range of human skin is developed. Compared with conventional E-skins, this TENG based self-powered E-skin can dynamically termoregulate according to the surrounding temperature through a phase change.

When: 2022-06-21, 09:35 - 10:00, Where: Parallel session 2

Self-powered Medical Devices and Electrical Stimulation Therapy

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Electrical activity is the basis of human life activities. Regulating electrical activity changes the excited and inhibited states of cells, tissues and organs to treat diseases. Nanogenerators are the new type of energy conversion device that convert low-frequency mechanical energy into electrical energy. In addition, it has gained the attention of researchers because of the flexibility, spinnability, high-output voltage, structural and material diversity. We employed nanogenerators to efficiently convert the mechanical energy of human motion into electrical energy and supply power to electrical stimulation devices and biosensors. Then, we developed self-powered electronic medical devices and medical sensors to carry out more systematic research work. For example, the power generated from the heartbeat can be used to drive the cardiac pacemaker to work for a long time, construct symbiotic cardiac pacemaker, as well as complete the research on improving heart rate and treating arrhythmia in the large animal experiments for the first time. Degradable self-powered electrical stimulation devices are used to regulate the growth direction of nerve cells, enhance intercellular integration and regulation of cardiomyocytes, promote osteoblasts proliferation and differentiation, accelerate skin wound healing. Besides, the devices can be completely absorbed by the body after the disease treatment. There are researches on self-powered cardiovascular biosensors that can realize minimally invasive implantation and have good biocompatibility. These researches focus on self-powered electronic medical devices and electrical stimulation therapy, and have important potential to be transformed into electronic medical devices and medical sensors for clinic treatment.

When: 2022-06-21, 12:25 - 12:50, Where: Parallel session 2

Self-Powered Triboelectric Pressure Sensors

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Zhen Wen[1]
[1] Soochow University

Abstract text: Pressure sensors have attracted much attention for their potential applications in health monitoring, wearable devices, electronic skin and smart robots, etc. With the rapid development of Internet of things, considering the large number and small scale of sensors, power consumption also plays a significant role in influencing their large-scale application. A new generation of self-powered pressure sensor based on triboelectric nanogenerator has been developed in terms of its incomparable advantages in power consumption and potential performance. Based on the coupling effects of triboelectrification and electrostatic induction, it enables to obtain the information on the mechanical input, e.g., magnitude and frequency, by analyzing electrical output signals. Intensive efforts have been devoted to improve the sensing performance of triboelectric pressure sensor to meet the demand of the practicality. In this talk, the key advancements in materials, structures and applications of self-powered triboelectric pressure sensors will be systematically introduced. Then, the theoretical basis, impact mechanism and the approaches to optimize the pressure sensing performance will be comprehensively analyzed. Afterwards, I will summarize the typical applications of triboelectric pressure sensors in different pressure ranges and working frequencies. Finally, the future perspectives of self-powered triboelectric pressure sensor will also be discussed.

When: 2022-06-21, 14:10 - 14:35, Where: Parallel session 2

Smart Sensors for Multiple Mechanical Stimuli Recognition

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Youfan Hu[1]
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Abstract text: Spatiotemporal recognition of multiple mechanical stimuli is essential for electronic skin (e-skin), which can provide more complete and accurate interaction information to enable elaborated functions, such as gesture recognition, object manipulation, and fine tactile discrimination. However, until now, in most e-skins, only perceiving mechanical stimuli has been realized; discriminating and identifying mechanical stimuli of different types, magnitudes, and directions is still a great challenge. This is mainly due to the nonspecific response of the sensor that makes it can be actuated by multiple stimuli to obtain ambiguous information and the degraded performance of the sensor as a compromise for system integration. Recently, we realized a bioinspired e-skin that can measure strain, shear, and pressure independently and simultaneously with direction information using three-dimensional integrated, mechanically isolated multiple high-performance sensors. Real-time multi-touch gesture recognition, as an example of spatiotemporal recognition of multiple mechanical stimuli, and perception of a red bean (0.065 g) in the hand have been demonstrated.

When: 2022-06-22, 08:50 - 09:15, Where: Parallel session 2

Sound-driven triboelectric nanogenerators: structure design, power management and self-powered multifunctional sensors

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Haiwu Zheng[1]
Yonghui Wu[1], Jiawei Zhang[1], Zhixin Wang[1], Hongbo Yao[1]
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Abstract text: Sound energy as a ubiquitous and renewable energy is extensively distributed in every corner of the world, such as the noise from factory machines and construction sites. Besides, with the development of the Internet of Things (IoT), the power supply to trillions of IoT nodes has become a serious challenge. The main content of this presentation contains two parts. (1) As inspired by an embroidery hoop, a new type of TENG without the Helmholtz resonant cavity is developed for collecting sound energy, which can generate the Voc and Isc up to 500 V and 124 μA, respectively at a resonance frequency of 170 Hz and sound pressure of 110 dB. Furthermore, the sound-driven TENG integrated with a specially designed power management circuit derived from the universal power management strategy (PMS) can successfully drive a commercial narrow band-IoT wireless node, which realizes periodic temperature and humidity data acquisition and transmission.(2) a low-cost, sound-driven triboelectric nanogenerator (SDTENG)-based self-powered sensor is proposed. The SDTENG-based sensor has been integrated with a deep learning technique in the present study to construct an intelligent sound monitoring and identification system, which is capable of recognizing a suite of common road and traffic sounds with high classification accuracies of 99% in most cases. The novel SDTENG-based self-powered sensor combined with deep learning technique demonstrates a tremendous application potential in urban sound management.

Main References

1. Haiwu Zheng et al, Adv. Funct. Mater. 2022, 2112155
2. Haiwu Zheng et al, Adv. Funct. Mater. 2021, 31, 2103081.

When: 2022-06-22, 08:00 - 08:25, Where: Parallel session 2

Transparent triboelectric nanogenerator using cellulose as sustainable building block for touching recognition

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Wenshuai Chen[1]
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Abstract text: Portable, low-cost and transparent triboelectric nanogenerator (TENG) is important for emerging electronics and energy devices. However, it remains difficult to construct transparent and foldable TENG to meet the demands of various three-dimensional space. We simply produced cellulose-based TENG by sequentially depositing a cellulose triboelectric layer, a silver nanowire electrode layer and a protective cellulose layer. The as-generated TENG is transparent, flexible and foldable. Furthermore, four TENGs were assembled onto one piece of cellulose film. The TENG-array film can accomplish various spatial configurations by a series of cutting and folding processes. Through signal processing circuit design, we used the TENG-containing cellulose-based multilayer film to fabricate a multi-dimensional touch password switch. The thin, flexible, foldable and transparent TENG has potential for developing film-based intelligent electronics.

When: 2022-06-22, 09:35 - 10:00, Where: Parallel session 1

Triboelectric Potential Driven FETs for Interactive Neuromorphic Synaptic Devices and Systems

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Qijun Sun[1]
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Abstract text: Fully imitating functions of biological synapses or afferents is critical to the evolution of neuromorphic computation and artificial intelligence. Integration with sensory, processing, and actuating components further endows the traditional neuromorphic devices with more complete bionic somatosensory ability. The seamless and adaptive interactions between neuromorphic synaptic devices and external environment is believed to be essential in establishing future brain-like computers and artificial intelligent systems. This presentation will introduce interactive neuromorphic synaptic devices and systems based on our recent research work of artificial afferents, bioinspired analogous nerves, myoelectric-mechanical interface, etc.

This talk will mainly cover the significant progress concerning on artificial synapses correlated with mechanical, optical, pressure and strain trigger-signals. Based on our researches of artificial afferent, mechanoplastic neuromorphic devices, and bioinspired mechano-photonic synapses, “interactive neuromorphic device” will be the core in this presentation. This talk will start from the principle of neurosynaptic devices activated by different sensing signals and introduce the influence of external signals on synaptic plasticity. It will also introduce the research progress of interactive neuromorphic synaptic devices/systems inspired by pressure, touch, displacement, light, heat, and mixed signals, and look forward to the future applications of interactive neuromorphic synaptic devices/systems. The interactive neuromorphic synaptic device will involve electronic devices, neuromorphic computation, sensors, and human-machine interactions, which is highly promising for revolutionary artificial synapse and neuromorphic systems.

When: 2022-06-22, 10:00 - 10:25, Where: Parallel session 1

Wireless Self-Powered Sensor Systems and Their Applications in Healthcare Monitoring

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

Yannan Xie[1]
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Abstract text: Recently, wearable sensors have experienced a rapid development and are greatly desirable for commercial, medical, and military applications. Among them, the self-powered sensing technology has been recognized to be a promising sub-category and exhibit vast potential in healthcare and biomedical monitoring, prosthesis development, sport sensing, and human-machine interfacing. The self-powered active sensor will generate electricity as a response to the external stimuli and the electric signal can reversely reflect the impact of the outside trigger. Therefore, it is able to effectively and independently work without any external power sources. Originated from Maxwell's displacement current, triboelectric nanogenerator (TENG) based on a coupling of triboelectric effect and electrostatic induction has been developing rapidly for self-powered active sensor. Here, we report a series of wireless self-powered sensors and their applications in healthcare Monitoring. Firstly, a seesaw structure TENG (SS-TENG) has been proposed based on vertical contact-separation working mode. Thanks to the asymmetric structure, the SS-TENG can be adopted to monitor the motion direction and velocity of moving objects. Being integrated with shoes or insoles, the SS-TENG can detect the foot posture under natural human motion. Secondly, a self-powered breath sensor based on the angle-shaped TENG has been demonstrated to monitoring the pulmonary function of human. Therefore, the above discussed wearable TENGs may provide a new prospect for self-powered active healthcare and biomedical sensors and have potential applications in the fields of healthcare monitoring, human-machine interfacing, and prosthesis developing.

When: 2022-06-22, 10:00 - 10:15, Where: Parallel session 2

Harvesting raindrop energy in harsh environments: Integrating triboelectric nanogenerator (TENG) with slippery lubricant-infused surfaces (SLIPS)

1.4 Blue energy
1. Triboelectric nanogenerators

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Abstract text: Liquid-solid triboelectric nanogenerators (TENG) have emerged as suitable devices to harvest widely abundant raindrop energy, which is essential to supply the rapid developments of the Internet of Things (IoT). However, TENG devices for raindrop energy harvesting need to be operated in variable atmospheric conditions, including high temperature/high humidity (e.g., rainforest) and cold environment (e.g., arctics). To address such limitations, slippery lubricant-infused porous surfaces (SLIPS) were integrated as a key TENG component to perform reliable energy harvesting ability in a wide operation window. In this report, we combine SLIPS with transistor-inspired architectures to develop a robust single-electrode triboelectric nanogenerator (SLIPS-SE-TENG) that is shown to operate effectively under extreme temperature and humidity. Throughout theoretical calculations and atomic force microscopy measurements, we showed that a small volume of lubricant oil is sufficient to produce a low water contact angle hysteresis, leading to efficient energy conversion, provided the droplet's moving velocity on the surface surpasses a threshold (0.3 mm/s). As such, we demonstrate SLIPS-SE-TENG to generate an instantaneous short-circuit current of 3 μA (charge density 8.8 nC/cm^2). Most importantly, SLIPS-SE-TENG could perform normally and stably in harsh conditions, such as high/low temperature, high humidity, low pressure, and/or wear. In general, SLIPS-SE-TENG could break through the limitations of traditional superhydrophobic surfaces, especially broadening the application range for raindrop energy harvesting.

When: 2022-06-22, 09:35 - 10:00, Where: Parallel session 2

Design, fabrication, and evaluation wave driven triboelectric nanogenerator guided by computational fluidic dynamics

1.4 Blue energy
1. Triboelectric nanogenerators

Yunzhong Wang[1]
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Abstract text: Since the environmental regulations are becoming more and more stringent to limit greenhouse gas exhaust, the conventional thermal power generator needs a renewable and sustainable alternative urgently to satisfy the increment of the electricity demand. Ocean wave energy converter becomes one of the top priority research hotspots.

The annual global ocean wave power potential is estimated to reach nearly 93,000 TWh, and the ocean wave energy around the coastlines is estimated to be 2–3 TW. For example, the place that Flinders university located, has a 4,204 km coastline that can provide sufficient ocean wave energy to generate electricity. The emerging triboelectric nanogenerator (TENG) provides an excellent capacity to harvest electrical energy from wave energy. In this study, a wave driven (WD) TENG prototype had designed based on the contact and separation mode and cost-effectively fabricated by using recyclable materials and 3D printing technologies. The geometry of the WD-TENG had optimized, and the wave frequency and amplitude had simulated experimentally to evaluate the WD-TENG performance under various ocean conditions. The computational fluidic dynamics (CFD) result was used to speculate on the movement of the WD-TENGs.
Based on the measurement result, about 7100 WD-TENGs can provide 7.5 kWh of electricity per day, and these can provide enough electricity for a family consisting of two adults and a child in the remote coastline area or island. It also shows excellent durability under eight hours of continuous operation and demonstrates strong adaptability under different frequencies and amplitudes of ocean waves.

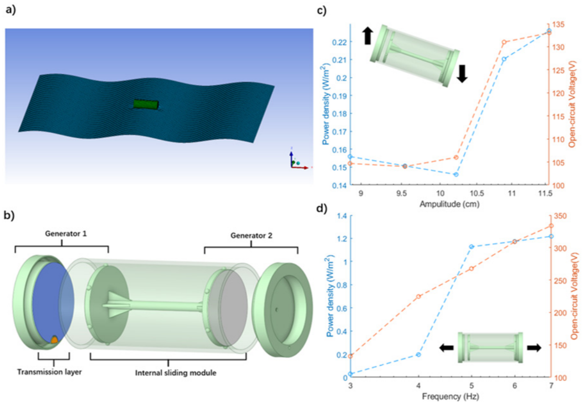

Figure. X. (a) Hydrodynamic model of the WD-TENG. The length of the WD-TENG is in the X direction (red) and the radius direction of the WD-TENG is in the Y direction (green) in the simulation, (b) The exploded view drawing of the WD-TENG with the components, (c) Effect of external amplitude on the output voltage and the power density of the WD-TENG, and (d) Effect of external frequency on the output voltage and the power density of the WD-TENG.

When: 2022-06-22, 10:15 - 10:30, Where: Parallel session 2

Performance assessment of triboelectric nanogenerators based on rolling spheres motion in realistic sea states

1.4 Blue energy

1. Triboelectric nanogenerators

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Abstract text: Ocean related activities are often supported by offshore equipment with power demands. These are usually deployed at remote locations and have limited space, thus small energy harvesting technologies, such as photovoltaic panels or wind turbines, are used to power their instruments. However, the inherent energy sources are intermittent and have lower density and predictability than an alternative source: wave energy. The triboelectric nanogenerator (TENG) is a promising and efficient energy harvesting technology capable of addressing these problems as it can efficiently convert regular/irregular mechanical energy into electrical power based on the triboelectrification and electrostatic induction effects. In this work, three TENGs based on rolling-spheres were developed and their performance compared in both a "dry" bench testing system under rotating motions, and in a large-scale wave basin under realistic sea-states installed within a scaled navigation buoy. The experiments showed that the electrical outputs of these TENGs tend to rise with increasing pitch amplitudes and decreasing period due to the increase of the spheres' velocity. The capability of these TENGs to harvest energy from ocean waves when incorporated into a navigational buoy was demonstrated under realistic sea states. The voltage generated by the TENGs achieves maximum values for periods close to the natural period of the scaled buoy (0.92 s). The wave basin tests clearly demonstrated a significant dependency of the electrical outputs on the pitch degree of freedom and the need to consider the full dynamics of the buoy, and not only that of TENGs, when subjected to the wave's excitations.

2. Piezoelectric nanogenerators

When: 2022-06-22, 12:50 - 13:15, Where: Parallel session 2

A method for quantitatively separating the piezoelectric component from the as-received "Piezoelectric" signal

2.1 Fundamentals

2. Piezoelectric nanogenerators

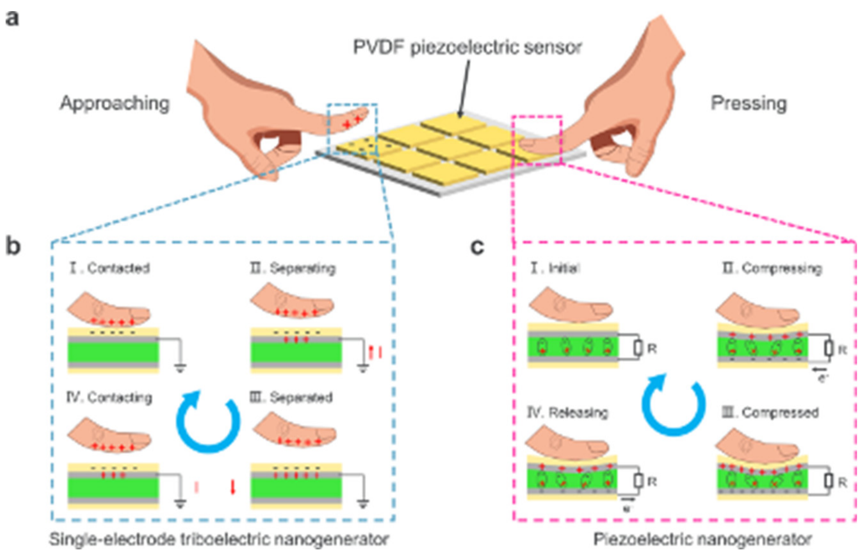
Chaojie Chen[1, 2]

Yunlong Zi[2], Cheng Yang[1]

[1] Institute of Materials Research, Tsinghua Shenzhen International Graduate School, Tsinghua University, Shenzhen, PR China.

[2] Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong Shatin, N.T., Hong Kong, China.

Abstract text: Polymer-based piezoelectric devices are promising for developing future wearable force sensors, nanogenerators, and implantable electronics, etc. The electric signals generated by them are often assumed as solely coming from the piezoelectric effect. However, triboelectric signals originated from contact electrification between the piezoelectric devices and the contacted objects can produce non-negligible interfacial electron transfer, which is often combined with the piezoelectric signal to give a triboelectric-piezoelectric hybrid output, leading to an exaggerated measured "piezoelectric" signal. Herein, a simple and effective method is proposed for quantitatively identifying and extracting the piezoelectric charge from the hybrid signal. The triboelectric and piezoelectric parts in the hybrid signal generated by a poly(vinylidene fluoride)-based device are clearly differentiated, and their force and charge characteristics in the time domain are identified. This work presents an effective method to elucidate the true piezoelectric performance in practical measurement, which is crucial for evaluating piezoelectric materials fairly and correctly.



When: 2022-06-22, 12:25 - 12:50, Where: Parallel session 2

Recent Advances in Scalable Biocompatible Piezoelectric Materials and Composites toward Future Manufacturing

2.1 Fundamentals
2. Piezoelectric nanogenerators
Xudong Wang[1]
[1] University of Wisconsin-Madison

Abstract text: Nanogenerator (NG) has been considered as a promising solution to biomechanical energy harvesting inside human body. So far, many technology innovations have advanced the NG technology toward a broad range of biomedical applications. Fundamentally, materials design and engineering draw the boundary where this technology may advance. In this talk, I introduce our most recent development of piezoelectric materials and composites that are particularly designed for implantable NG applications. First, I present our wafer-scale approach to creating piezoelectric biomaterial thin films based on γ glycine crystals. The self-assembled sandwich film structure enabled both strong piezoelectricity and largely improved flexibility. Then, new ferroelectric composites are presented as a new material used in 3D printing for directly manufacturing of piezoelectric architectures with tunable piezoelectric and mechanical properties. Toward the end, novel applications of implantable piezoelectric materials are introduced, which enable the closed-loop electrostimulations for many biomedical therapeutics.

When: 2022-06-22, 13:15 - 13:30, Where: Parallel session 2

Perspectives on unconventional effects on piezoelectric energy harvesters: from ceramics to biopolymers

2.1 Fundamentals
2. Piezoelectric nanogenerators

Chang Kyu Jeong[1]
[1] Jeonbuk National University

Abstract text: This invited speech discusses recent research achievements about the new or modified mechanisms of piezoelectric energy harvesting materials using from ceramic particles to biological polymers. First, the flexoelectric influence on the piezoelectric core-shell nanoparticles will be explained. Because of the lattice mismatch between core and shell parts in the nanoparticles, our group can expect the strain gradient effect inducing flexoelectricity. Secondly, the representative piezoelectric polymer, P(VDF-TrFE), will be discussed. Recently, there are some reports showing that the behavior reminiscent of morphotropic phase boundary (MPB) can be also emerged in the P(VDF-TrFE) ferroelectric copolymeric compositions. In addition, the relaxor-based phase competition has been also studied. Our group has validated that this intriguing phenomenon can also occur in the electrospinning configuration of P(VDF-TrFE), and found the enhanced performance of flexible energy harvesters. Finally, our group has found specific piezoresponses of silk biopolymers. It is highly related molecular bonds such as hydrogen bonding.

When: 2022-06-22, 12:00 - 12:25, Where: Parallel session 2

Polarity and Doping in Chemically Deposited ZnO Nanowires for Piezoelectric Nanogenerators

2.1 Fundamentals
2. Piezoelectric nanogenerators

Vincent Consonni[1]
[1] Université Grenoble Alpes, CNRS, Grenoble INP, LMGP, 38000 Grenoble, France

Abstract text: As a biocompatible piezoelectric semiconductor composed of abundant elements, ZnO as nanowires has emerged as a highly promising material for piezoelectric nanogenerators [1]. The chemical bath deposition in aqueous solution offers a great opportunity to form ZnO nanowires on large surface area at low cost and low temperature [2]. However, it raises several critical issues related to polarity and doping [3], which should be addressed with care to boost the performances of ZnO nanowire-based piezoelectric nanogenerators. First, O- and Zn-polar ZnO nanowires are generally formed in the arrays [4], mixing the polarity and hence reducing strongly the output voltage. Second, the growth medium of ZnO nanowires is full of hydrogen [5], inducing a massive incorporation of related defects as shallow donors and thus screening the piezoelectric potential. In this context, we review how the polarity of ZnO nanowires affects the nucleation and growth mechanisms, defect incorporation, and electrical contact. A special emphasis is further placed on the residual and intentional doping of ZnO nanowires in aqueous solution, including the Cu and Sb dopants. Finally, optimization guidelines of the piezoelectric nanogenerators are given with a focus on the morphology and properties of ZnO nanowires.

[1] X. Wang et al., Science 316, 102-105 (2007)

[2] L. Vayssières et al. The Journal of Physical Chemistry B 105, 3350-3352 (2001)

[3] V. Consonni et al. Nano Energy 83, 105789 (2021).

[4] V. Consonni et al. ACS Nano 8, 4761 (2014).

[5] J. Villafuerte et al. The Journal of Physical Chemistry C 124, 16652 (2020)

When: 2022-06-22, 14:10 - 14:25, Where: Parallel session 2

All polymer based stretchable piezoelectric nanogenerators (S-PENG) for wearable energy harvesting

2.2 Micro-nano-power sources
2. Piezoelectric nanogenerators

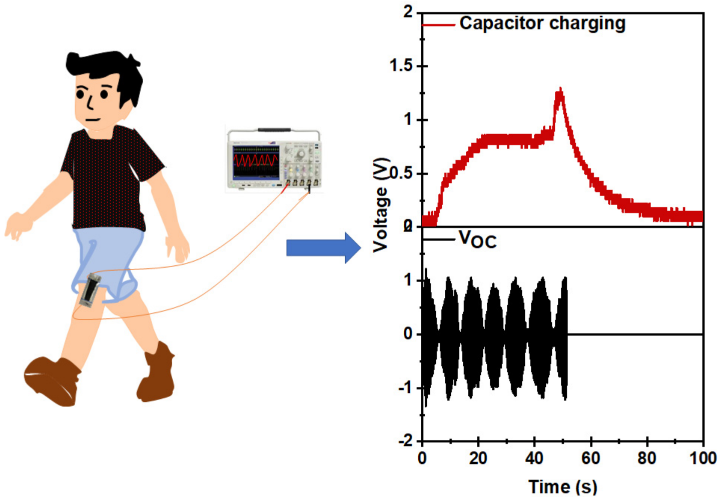
Gurneet Kaur[1]
Jagan Singh Meena[1], Manjeet Jassal[1], Ashwini Agrawal[1]
[1] SMITA Research Lab, Centre of Excellence in Smart Textiles, Department of Textile and Fibre Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India.

Abstract text: Piezoelectric nanogenerators (PENG) are desirable candidates for wearable electronics due to their simple structure and ease of generating green energy. However, these suffer from poor stability to repeated deformations, such as stretching.

To integrate nanogenerators with the wearables, they are required to be highly stretchable and mechanically stable to repeated deformations. However, PVDF, though provide flexibility, show poor stretchability, and low output voltages.

In the present study, we report, for the first time, the fabrication of all polymer based highly stretchable piezoelectric nanofiber films. Piezoelectric polymer, PVDF, which is known to have poor stretchability and low piezoelectric response, was blended with a small amount of elastic (non-piezoelectric) polymer to achieve significant enhancement of properties. The blend could give a unique combination of highly stretchable electrospun composite nanofibrous webs with significantly enhanced piezoelectric properties and high stability to repeated deformations. Using a novel stretchable electrode, the device could be readily integrated with the wearables and the energy could be harvested from human motions and stored in a capacitor

The S-PENG devices were integrated with the wearables and evaluated for their performance during different body motions such as walking, knee and elbow bending, and finger movements. The device produced $0.5\mu Wcm^{-1}$ power density which is sufficient to source power to nano and micro power sources devices.


Capacitor charging
Voc
Voltage (V)
Time (s)
2
1.5
1
0.5
0
1
0
-1
-2
0
20
40
60
80
100

When: 2022-06-22, 14:40 - 14:55, Where: Parallel session 2

Ethylene glycol doped PEDOT: PSS for effective p-n junction based ZnO piezoelectric nanogenerator

2.2 Micro-nano-power sources
2. Piezoelectric nanogenerators

Yuan Zhang[1]
Qinrong He[1], Joe Briscoe[1]
[1] Queen Mary University of London, School of Engineering and Material Science and Materials Research Institute, UK

Abstract text: With the increasing awareness of environmental protection, more and more efforts are put into the development of renewable and clean energy. Mechanical energy is one of the most abundant and accessible energy sources, and has been widely harvested by large-scale technologies such as wind power or tidal stream generators. Piezoelectric nanogenerators (PENGs) can convert small mechanical energy such as body motion or vibration into electricity, which can be used to power small portable electronics, medical bio-implants, remote wireless sensors etc. P-n junction based ZnO PENGs have attracted interest due to their good flexibility, simple manufacture process and low raw material cost.

Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonic acid) (PEDOT:PSS) has been employed in the p-n junction based ZnO PENGs owing to its good film-forming properties, high transparency, tunable conductivity, and excellent thermal stability. P-type PEDOT:PSS can form a p-n junction with n-type ZnO nanorods, which slows down the screening of the piezoelectric polarisation to generate the output voltage. Therefore, optimizing the conductive property of PEDOT:PSS is a potential way to improve the performance of PENGs by controlling screening of piezoelectric polarisation and reducing internal resistance of the device. In this work, ethylene glycol (EG) is doped into the p-type PEDOT:PSS layer in ZnO PNGs to modify the conductivity of PEDOT:PSS. It is found that modest EG doping can effectively enhance the conductivity of the PEDOT:PSS layer and reduce the internal resistance of ZnO NG device. However, devices without EG doping or using excess EG doping can result in worse performance.

When: 2022-06-22, 14:25 - 14:40, Where: Parallel session 2

Piezoelectric Nanogenerator Based on 2H-1T Heterostructures of MoS2 Nanosheets

2.2 Micro-nano-power sources

2. Piezoelectric nanogenerators

Charu Sharma[1, 2]

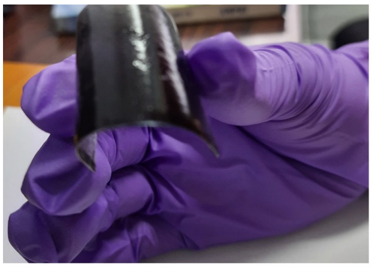
Simadri Badatya[1, 2], Avanish Kumar Srivastava[1, 2], Manoj Kumar Gupta[1, 2]

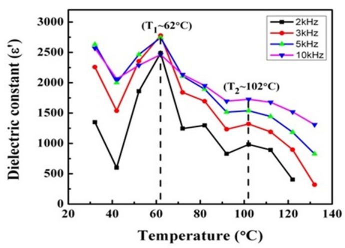
[1] CSIR-Advanced Materials and Processes Research Institute, Bhopal, M.P -462026, India

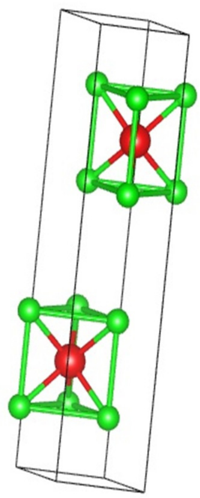
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India

Abstract text: Because of the inherent piezo and semiconducting properties, two dimensional materials have gained immense attraction in research community in recent years. We have demonstrated the fabrication of piezoelectric nanogenerator (PENG) based on dual phase of MoS_2 nanosheets. Raman investigation reveals the formation of few-layer MoS_2 nanosheets (Hydrothermally grown) with the coexistence of dual semiconducting (2H) and metallic (1T) phases. In dielectric studies, a very high dielectric constant (ε′) of 2612 and an unusual dissipation factor of 250 were observed at 1kHz frequency at room temperature compared to bulk MoS_2 (ε′ ~ 19). The unusual high dielectric constant and high dissipation factor from MoS_2 nanosheets may be due to the nanoscale-driven large polarization density and coexistence of the metallic phase in MoS_2, respectively. Piezoelectric nanogenerator exhibits an excellent high output voltage of 22 V and output current density of 9μA/cm² under vertical compressive force of 2 kgf. High output voltage and current density was discussed in terms of high d_{33} and dielectric constant.

Keywords: 2D material, Piezoelectric nanogenerator, Dual phase, Dielectric studies







Piezoelectric properties and prediction of monolayer molybdenum disulfide nanosheets

2.2 Micro-nano-power sources
2. Piezoelectric nanogenerators

SANG A HAN[1, 2]
Sang-Woo Kim[2, 3], Jung Ho Kim[1]
[1] Institute for Superconducting and Electronic Materials, Australian Institute for Innovative Materials, University of Wollongong, Squires Way, North Wollongong, NSW 2500, Australia
[2] School of Advanced Materials Science & Engineering, Sungkyunkwan University (SKKU), Suwon 16419, Republic of Korea
[3] SKKU Advanced Institute of Nanotechnology (SAINT) and Samsung Advanced Institute for Health Sciences & Technology (SAIHST), Sungkyunkwan University (SKKU), Suwon 16419, Republic of Korea

Abstract text: Two-dimensional (2D) materials have piezoelectric properties despite having an atomic layer thickness. The reason why the piezoelectric properties of 2D materials are of interest is because they have a high piezoelectric constant and flexibility in the plane direction, so they react very sensitively to the shape deformation of the material. And through this, it is possible to generate various electrical signals by high-efficiency piezoelectric and transformation properties. However, defects inevitably occurred in the process of synthesizing materials cause a screen phenomenon, causing a problem that lowers the piezoelectric property and output performance. Various attempts have been reported to overcome this. In this study, the piezoelectric properties of monolayer molybdenum disulfide (MoS_2) among 2D materials with piezoelectric properties are explained through experimental results. In addition, to overcome the screen phenomenon, we describe the results of improved MoS_2 piezoelectric properties through defect passivation through sulfur treatment and carrier control through novel metal doping.

When: 2022-06-22, 13:45 - 14:10, Where: Parallel session 1

Self-powered Flexible Devices: Piezo-sensor and microLED

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

Keon Jae Lee[1]
[1] Department of Materials Science and Engineering, KAIST

Abstract text: This seminar introduces two recent progresses of self-powered flexible devices; piezo-sensors and microLED. The first part will introduce flexible inorganic piezoelectric membrane that can detect the minute vibration of membrane or human skin that expands the application of self-powered acoustic sensor and blood pressure monitor. Speaker recognition has received spotlight as a next big thing of voice user interface such as personalized voice-controlled assistant, smart home appliance, biometric authentication. The conventional speaker recognition was realized by a condenser type microphone, which detects sound by measuring the capacitance value between two conducting layers. The condenser type microphone, however, has critical demerits such as low sensitivity, high power consumption, and an unstable circuit due to the large gain amplification. Speaker recognition also suffers from a low recognition rate, caused by limited voice information and optimal algorithms for a simple and accurate process. Herein, we reported a machine learning-based acoustic sensor by mimicking the basilar membrane of human cochlear. Highly sensitive self-powered flexible piezoelectric acoustic sensor (f-PAS) with a multi-resonant frequency band was employed for voice recognition. The speech waveforms were recorded by the multi-channel f-PAS and converted into frequency domain signals by using Fast Fourier Transform to obtain the characteristics of voice frequency. Convolutional Neural Network (CNN) were utilized for speaker recognition, resulted in a 97.5% speaker recognition rate with the 75% reduction of error rate compared to that of the reference MEMS microphone. The second part will discuss the highly efficient flexible vertical micro LED (f-VLED) for displays and biomedical applications.

When: 2022-06-22, 12:00 - 12:25, Where: Parallel session 1

Towards self-powered sensors based on hydraulic pressure energy harvesting

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

Sebastian Bader[1]
Bengt Oelmann[1]
[1] Mid Sweden University

Abstract text: Hydraulic systems are commonplace in industrial applications. As these systems operate based on hydraulic power, an electrical infrastructure is typically not needed. Electrical power, however, is required for sensors and their readout electronics, which in turn are needed to enable system control, condition monitoring and predictive maintenance. In order to avoid battery-based power supplies, energy harvesting is a desirable alternative. This presentation will describe and discuss a case study of hydraulic pressure energy harvesting for self-powered sensors. Although energy could be harvested from multiple sources in hydraulic systems, hydraulic pressure has the benefit that it is inherent to the system. In the case study, piezoelectric transducers are used to convert the pressure ripple into an electrical output. It will be discussed what influences the fluid-to-transducer interface has; how the output response can be improved with the help of acoustic resonators; and what AC-DC power management strategies are applicable to the investigated system. As a result, a holistic system picture, from source to load will be provided.

When: 2022-06-22, 14:10 - 14:35, Where: Parallel session 1

Piezotronics in GaN

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

Weiguo Hu[1]
[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, P. R. China

Abstract text: Group III nitrides are the third-generation semiconductor, which have important applications in many fields, such as lighting, display, power devices and so on. Group III nitrides have strong spontaneous polarization/piezoelectric polarization characteristics. The piezotronic effect proposed by Prof. Z.L.Wang in 2006 points out that the piezoelectric polarization electric field can effectively modulate the band structure of the device, which affects the key physical processes such as quantum transition, recombination and carrier transport, thus restricting the performance of electronic and optoelectronic devices.

We developed some novel piezoelectric devices, such as AlGaN/GaN high electron mobility transistors (HEMTs) and micro cantilever Stress regulated power device (SPD). High performance AlGaN/GaN HEMTs are developed. The modulation mechanism of piezotronic effect on HEMTs is confirmed theoretically and experimentally. The SPD is designed based on piezoelectric electronics, which can realize the direct, real-time and programmable control of high-power density power by weak mechanical signal. This new type of intelligent power device can greatly simplify the system complexity, greatly reduce the system cost, and improve the reliability and reliability, which is conducive to the construction of multi-channel parallel, distributed and automatic control network, further reducing the impact of some unit failures on system stability.

These studies further deepen our understanding of piezotronics, and provide a new way to optimize the performance of GaN power devices. More importantly, they are expected to develop new applications in important scientific and technological frontiers such as autonomous driving, bionic robot, automatic control and so on.

When: 2022-06-22, 14:50 - 15:05, Where: Parallel session 1

A Wearable Piezoelectric Sensor Based on ZnO/Liquid Metal Heterostructures for Human-Related Information Extraction

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

Jing Jiang[1]
Wenzhuo Wu[1]
[1] School of Industrial Engineering, Purdue University

Abstract text: Self-powered intelligent sensors with high stretchability and high biocompatibility are critical in next generation of wearable human-related information extraction. In this article, we reported a facile, energy-effective synthesis of ZnO nanorods (NRs) on the liquid metal (LM, the composition is Ga-In eutectic alloy (EGaIn)) electrode and the integration of the ZnO NRs/LM with Ecoflex to form a soft piezoelectric wearable. During the process, Ecoflex substrate with LM pattern was directly put on the hydrothermal bath, undergoing a vertical, selective growth of ZnO NRs exclusively on LM surface. The physical and chemical properties of the integrated ZnO NRs/LM/Ecoflex were systematically explored and leveraged to achieve optimized piezoelectric power collection. The softness and the stretchability of the Ecoflex/ZnO NRs/LM/Ecoflex device made it possible for it to be worn conformably to different parts of human body such as throat, fingertips, wrist, etc., efficiently converting the subtle mechanical vibration from human physiological activities (voice, pulse, etc.) to measurable electric signals. Our work provides a novel device structure of ZnO based PENG and demonstrates its potential application on self-powered human wearables in the field of real-time collection of human vocal movement as well as comfortable monitoring of human cardiac health.

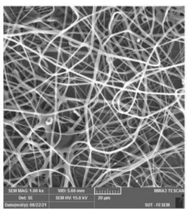
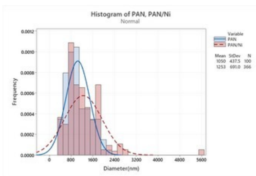
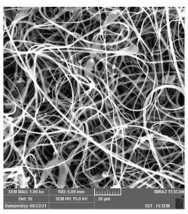
When: 2022-06-22, 12:55 - 13:10, Where: Parallel session 1

Graphene spin-coated electrode for polyacrylonitrile acoustic nanogenerators

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

Sedigheh Aghayari[1]
[1] Sharif University of Technology

Abstract text: In recent years, piezoelectric nanogenerators have become more attractive than triboelectric nanogenerators due to their more excellent durability in high dust or humidity. Therefore, increasing their outputs is the subject of many studies. Here the focus is on electrodes of acoustic nanofiber nanogenerators for the first time. Compared to other works here, introducing a new electrode is the aim, and it should be cheap and does not result in lower outputs. Here, for the first time, graphene spin-coated ink was used for a polyacrylonitrile-based (PAN) acoustic nanogenerator, which gave the output of 60 mV. The results of the acoustic tests were compared with the in situ synthesis of nickel nanoparticles on the layer using graphene spin-coated screen ink and conductive tape, which had the highest outputs of 0, 60 and 120 mV. The field emission scanning electron microscope (FESEM) images and average nanofiber diameter are presented in Table 1. From the results, it is clear that the in situ synthesis of nickel (Ni) resulted in a broader distribution and higher average diameter of the nanofibers. Additionally, the best way for increasing the output of piezoelectric acoustic nanogenerators is make composites. Up to now the highest piezoelectric effect is for PAN and its composites has not investigated yet. Here, as a first step of doing works in this field, I used copolymer of PAN, because PAN is not a good polymer for doping and it needs functional groups.

Sample code	FESEM image	Diameter distribution
PAN		
PAN/Ni		

When: 2022-06-22, 14:35 - 14:50, Where: Parallel session 1

High Humidity Resistant Flexible Hydrophobic Nanogenerator

2.3 Self-powered sensors and devices

2. Piezoelectric nanogenerators

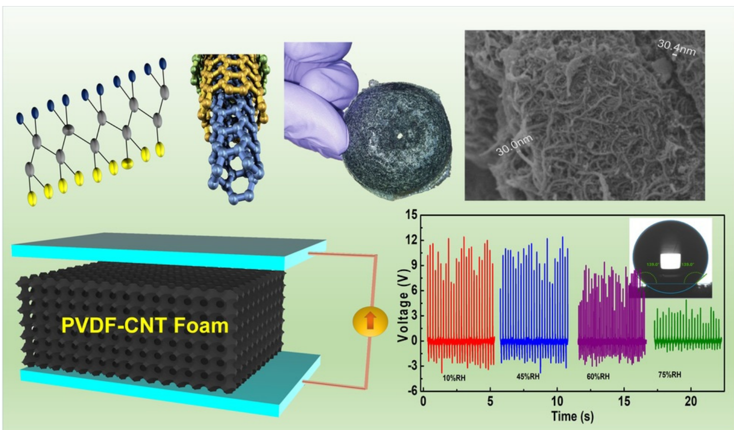
Simadri Badatya[1]

Charu Sharma[1], Natrajan Sathish[1], Manoj Kumar Gupta[1]

[1] CSIR-Advanced Materials and Processes Research Institute, Bhopal, M.P -462026, India Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India

Abstract text: Light weight lead free, polymer and carbon nanotube based flexible piezoelectric nanogenerators have prompted widespread concern for harvesting mechanical energy and powering next generation electronics devices. Herein, light weight polyvinylidene fluoride (PVDF)-carbon nanotube (CNT) foam was prepared to fabricate humid resistant hydrophobic flexible piezoelectric nanogenerator for harvesting mechanical energy for the first time. Hydrophobic piezoelectric PVDF-CNT foam with density of 0.15 g/cc was prepared though solution route. PVDF-CNT foam exhibited crystalline well-defined chain like structure with 65 % fraction of β-phase. Piezoelectric coefficient (d_{33}) of 9.4 pC/N was obtained from self-poled PVDF-CNT foam. High d_{33} of PVDF-CNT foam is caused by dipole alignment induced by local electric field by CNT in the microcellular structure of PVDF. The developed foam showed very high dielectric constant of 3087 at 150 Hz. Flexible piezoelectric PVDF-CNT foam based nanogenerator was fabricated, which showed high output voltage of 12 V and current density of 30 nA/cm^2 respectively under small vertical pressure of 0.02 kgf. Piezoelectric output performance was measured under different humid condition and an output voltage up to 9 V was observed even under 60 % RH condition. PVDF-CNT foam exhibited a hydrophobic behaviour, with a high surface water contact angle of 139^o. . Such high output voltage even under small pressure, without applying electrical poling and under humid condition was originated though CNT induced self-alignment of electric dipoles in PVDF polymer.These excellent performances confirmed the potential of developed foam based device for organic based ultrasensitive self-powered nanosensors and nanosystems.

Keywords: PVDF, Carbon Nanotube, Piezoelectric Nanogenerators, Humidity



When: 2022-06-22, 12:25 - 12:40, Where: Parallel session 1

Piezoelectric Micro/Nanorobots for Wireless Deep Brain Stimulation

2.3 Self-powered sensors and devices

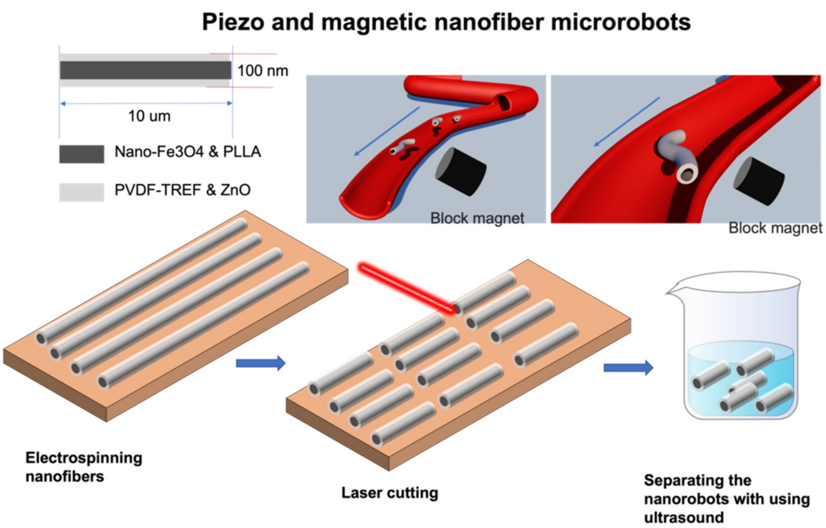
2. Piezoelectric nanogenerators

FAN WANG[1]

Metin Sitti[1]

[1] Physical Intelligence Department, Max Planck Institute for Intelligent Systems, 70569 Stuttgart, Germany

Abstract text: It is essential to our current understanding of neurobiology and in the diagnosis and treatment of neurological disorders that key therapeutic central nervous system (CNS) interventions is using sensing and/or modulation of neural electrical activity. For more than 30 years, deep brain stimulation (DBS) has provided patients with symptom relief from Parkinson's disease, as well as other disorders, using electrodes wired into deep targets within the brain. More recently, closed-loop control of epidural electrical stimulation enabled walking in patients with spinal cord injury. Such devices function in freely moving patients, enabling daily activity and chronic patient use. In recent years, efforts to make neural intervention less invasive, longer-lasting, and safer have progressed the capabilities of neural devices. A key challenge of such devices is powering, and wired-in powering can require that patients undergo surgical battery changes, every 3 to 5 years in the case of DBS devices. We present a piezoelectric and magnetic microrobot, which can be controlled by the magnet field, following the Cerebrospinal fluid circulatory system to approach to the deep brain neuro cells, and then be activated by wireless ultrasound to generate charge to stimulate the neuro cells. We fabricate the microrobots with PVDF-TREF & ZnO (shell) and Nano-Fe3O4 & PLLA (core) by Coaxial electrospinning. We also show that local subthalamic modulation promotes modulation in other regions connected via basal ganglia circuitry, leading to behavioral changes in mice. The magnetic and piezoelectric nanofibers present a versatile technology for less invasive, deep brain stimulation.



When: 2022-06-22, 12:40 - 12:55, Where: Parallel session 1

Predominant air-stable and eco-friendly halide perovskite nanostructures for the development of stretchable nanogenerator

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

Venkatraju Jella[1]
Swathi Ippili[1], Chongsei Yoon[2], Soon-Gil Yoon[1]
[1] Department of Materials Science and Engineering, Chungnam National University, Daeduk Science Town, 305-764, Daejeon, South Korea
[2] School of Electrical Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, South Korea

Abstract text: With the rapid advances in the Internet of Things (IoT), energy harvesting from environmental energy sources such as solar, thermal, and mechanical energies has received considerable attention to realize the self-operation of portable/wearable devices. Particularly, mechanical energy is a widely accessible energy source in our daily life. Piezoelectric nanogenerators (PENGs) are widely used to harvest mechanical energy, because of their direct power-conversion ability and easier manufacturing. Mainly, stretchable and eco-friendly PENGs are highly desirable for operating next-generation flexible portable/wearable electronic devices with a minimum stretching rate of 50%. Recently, many researchers have developed halide perovskites (HPs) based PENGs due to their high ferro/piezoelectric properties. However, most of the HP-based PENGs contain highly toxic lead, which is the major concern and limits their practical application in wearable electronics. Further, there have been no reports on stretchable nanogenerators using HPs demonstrated so far.

Herein, we demonstrate an eco-friendly and stretchable PENG based on $(CH_3NH_3)_2CuCl_4$ (MCC) and PDMS composite films for mechanical energy harvesting and sensing applications. The predominant air-stable lead-free MCC nanocubes were prepared using the antisolvent-assisted collision technique (ACT) under air-ambient conditions. While the MCC-PDMS composites were fabricated by mixing various contents of MCC (0-7 wt%) with PDMS and utilized to fabricate stretchable PENGs with the structure of Au/MCC-PDMS/Au. The PENG output performance was investigated and applied to wearable electronic devices with a more than 50% stretching rate. These PENGs exhibited high-performance, excellent mechanical robustness, and long-term stability over a period of time and could able to power small-scale electronic devices.

3. Hybridized nanogenerators

When: 2022-06-21, 10:00 - 10:15, Where: Parallel session 3

A Dual-rotation Shaft Hybrid Triboelectric Nanogenerator for Broadband Highly Efficient Wind Energy Harvesting

3. Hybridized nanogenerators

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Abstract text: Abstract: Triboelectric nanogenerators (TENG) for wind energy harvesting have exhibited huge potentials as renewable and distributed energy sources in the development of Internet of Things. However, the energy conversion efficiency is still challenged especially in the higher wind speed that should be compensated by electromagnetic generator (EMG). In this work, a hybrid triboelectric-electromagnetic nanogenerator (HTEG) is reported to effectively harvest wind energy over a broadband wind speed (2 m/s to 14 m/s). The HTEG is designed in a concentric dual-rotation shaft structure, in which the TENG and EMG with different shapes, sizes and arm lengths of wind cups are rationally coupled. The integration of the TENG and EMG with varied structural parameters achieves mutual compensation of their own efficient energy harvesting band, enabling the HTEG operates in a preferable aerodynamics with an average of 40% energy conversion efficiency output over a broad range of wind speeds. Furthermore, with the connected power management circuit, the HTEG is capable of driving several types of electronics and further demonstrates a self-powered sensor system by powering a thermometer. The proposed HTEG greatly expands its potential in large-scale wind energy harvesting and renders a highly efficient way toward energy conversion for self-powered sensor.

Keywords: triboelectric nanogenerator, wind energy harvesting, hybrid nanogenerator, dual-rotation shaft, self-powered system

When: 2022-06-21, 10:30 - 10:45, Where: Parallel session 3

Eco-friendly, biomass nanogenerators based on polysaccharide nanocomposites

3. Hybridized nanogenerators

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Abstract text: Circularity and sustainability of energy devices are gaining importance in the face of growing global energy demand, which expands the electronics waste as well as increases the scarcity of critical energy materials. Triboelectric nanogenerators (TENG), which have a great potential in providing renewable energy, often lack sustainability themselves as the constituting materials are mostly petrol-based, fluorinated polymers and metals.[1,2] Therefore, revalorized biomass like lignocellulosics and agri-food residues are increasingly considered as triboactive components.[3]

Here, we present preliminary results of eco-friendly nanogenerators based on different bionanocomposite films. Biopolymers like cellulose, lignin and alginate are investigated as matrix with different fillers such as nanocarbons and barium titanate (BTO) particles in order to tune the triboelectric and piezoelectric properties. In addition, the role of porosity is a further parameter under investigation both for the electrical output and complementary properties. Finally, contact-separation and single-electrode nanogenerators were constructed and tested for wind energy harvesting.[4]

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When: 2022-06-21, 10:15 - 10:30, Where: Parallel session 3

Foot-strike-actuated Triboelectric-electromagnetic Hybridized Nanogenerator for Biomechanical Energy Harvesting

3. Hybridized nanogenerators

Tiago Alves[1]
Cátia Rodrigues[1], Cândido Duarte[2], João Ventura[1]
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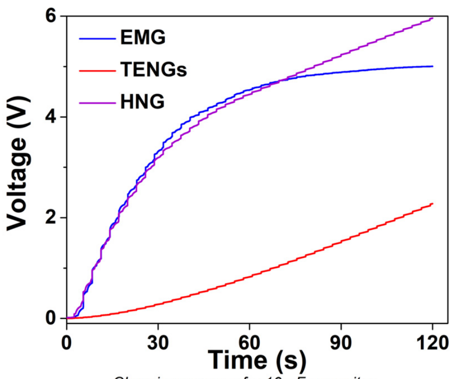
Abstract text: The increasing use of wearable electronics calls for sustainable energy solutions. These devices are normally powered by batteries, which need to be eventually replaced, leading to an increase in environmental pollution. Biomechanical energy harvesting appears as a potential solution, as the body generates sufficient power to drive small electronics during gait motion. Triboelectric nanogenerators (TENGs) emerge as a promising approach due to their light-weight and high power density at low frequencies. In this work, a TENG was hybridized with an electromagnetic generator (EMG) to harvest energy from the foot-strike. An enclosed radial-flow turbine, actuated by two air-bulb pumps, was optimized and used to convert the foot-strike low-frequency linear movement into a higher-frequency rotational motion.

A FEP film attached to one of the rotor blades acted as the negative tribomaterial, while a triboelectric brush made from animal fur served as the positive tribomaterial. A single TENG-unit operating in the freestanding mode generated an optimal power of 4.7 μW and transferred a short-circuit charge of 2.3 nC. Three TENG-units were then integrated via a full-wave rectifier to charge a 0.1 μF capacitor up to 91 V in 140 seconds. Four disk-shaped NdFeB magnets were attached on the rotor topside and the corresponding Cu coils were fixed on the stator above. The EMG generated a maximum power of 4.25 mW. Hybridizing the two generators increased by 7.2 and 1.4 times (compared with the TENGs and EMG, respectively) the energy stored in a capacitor, which was then used to power a digital pedometer.



Charging curves of a 10 μF capacitor.

Performance-enhanced stretchable piezoelectric nanogenerator based on multi-stacked flexoelectric ZnAl:LDH nanosheets and piezoelectric ZnO nanorods

3. Hybridized nanogenerators

Chongsei Yoon[1]
Venkatraju Jella[2], Swathi Ippili[2], Giwan Yoon[1], Soon-Gil Yoon[2]
[1] Korea Advanced Institute of Science and Technology
[2] Chungnam National University

Abstract text: Self-powered devices that can harvest energy from surrounding ambient have been proved to be an effective power supply without environmental contamination. Piezoelectric nanogenerators (PENGs), a significant way to convert mechanical energy into electricity, have been widely applied in energy harvesting as well as self-powered sensors of the internet-of-things (IoT). Particularly, stretchable PENGs are highly desirable for operating next-generation portable/wearable electronic devices. The ZnAl:LDH (layered double hydroxide) is a flexoelectric and eco-friendly material and can be grown facilely by dipping AZO thin film in DI-water. Besides, ZnO is a well-known piezoelectric material. However, there are no reports examining the nanogenerator performance by coupling the flexoelectric and piezoelectric effects in the ZnAl:LDH nanosheets and ZnO nanorods heterostructure.

We present a highly-stretchable flexoelectricity enhanced-piezoelectric nanogenerator (FPENG) based on ZnO nanorods and ZnAl:LDH nanosheets heterostructure prepared onto the stretchable polyurethane (PU) substrate. Initially, the stretchability of sputtered gold electrode onto the PU substrate was systematically examined by measuring the resistance change with applied strain. For ZnO-LDH FPENG, firstly vertically-aligned eco-friendly ZnAl:LDH Nanosheets were facilely synthesized on Au/PU substrate by dipping AZO/Au/PU film in DI-water. Then, omnidirectional ZnO nanorods were grown onto the LDH nanosheets via a hydrothermal method using ZnO thin film as a seed layer. Later, thin PDMS was spin-coated onto ZnO-LDH film and sputtered Au electrode. Further, the piezoelectric output performance of stretchable FPENG was measured under various modes of applied strain including tapping, bending, and stretching. Further, the real-time application of the same FPENG as a pressure/strain sensor was also demonstrated.

When: 2022-06-21, 09:35 - 10:00, Where: Parallel session 3

Self-Powered Nanomaterials, Devices and Systems for Healthcare and Environmental Applications

3. Hybridized nanogenerators

Zong-Hong Lin[1]

[1] National Tsing Hua University

Abstract text: By directly converting mechanical energy or thermal energy into electric outputs, the output values of the developed nanosensors will be varied upon the sensing of target molecules or ions. With the simplicity (no complex circuitry or power supply involved), low-cost fabrication (small-sized; minimal and low-priced materials required) and label-free sensing mechanism, the developed self-powered nanosensors demonstrate great potential to serve as new prototypes of portable devices for the in-field sensing of samples. Dr. Lin's group also utilized commercial textiles and proteins/hydrogels to fabricate biocompatible, portable, and lightweight nanogenerators to harvest biomechanical energy from human motions or thermal energy in the environment to directly power wearable electrochemical systems for humidity/temperature/sweat detections (ions, glucose, and lactate) and antibacterial applications. The developed wearable systems also show their adaptability to be integrated with next-generation smart clothes. In the other way, the highly reactive nature of reactive oxygen species (ROS) is the basis for widespread use in healthcare and biomedical research fields. However, conventional photocatalysts (like TiO_2) have been limited due to various environmental and physical factors. To address this problem, Dr. Lin's group reported piezoelectric (like MoS_2) and thermoelectric (like Bi_2Te_3, Sb_2Te_3 and PbTe) materials as piezocatalysts and thermocatalysts which can produce ROS (like $^{\cdot}OH$, $^{\cdot}O_2^-$ or H_2O_2). and result in the effectively oxidative damage of bacteria, which makes both of them highly promising for real-time disinfection applications. As a whole, the concepts presented here can open a new direction towards sustainable environmental remediation and biomedical applications.

When: 2022-06-21, 10:45 - 11:00, Where: Parallel session 3

Plasma engineering of microstructured piezo – triboelectric hybrid nanogenerators for wide bandwidth vibration energy harvesting

3. Hybridized nanogenerators

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Ali Ghafarinejad[1], Francisco Aparicio[1, 2], Javier Castillo-Seoane[1], Carmen Lopez-Santos[1, 2], juan pedro espinós[1], josé cotrino[1, 3], Juan Sanchez-Valencia[1], Angel Barranco[1], Ana Borras[1]
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[2] Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla, c/ Virgen de Africa 7, E-41011, Seville, Spain.
[3] Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, Avda. Reina Mercedes, E-41012, Seville, Spain.

Abstract text: We introduce herein the advanced application of low-pressure plasma procedures for the development of piezo and triboelectric mode I hybrid nanogenerators. Thus, plasma-assisted deposition and functionalization methods are presented as key enabling technologies for the nanoscale design of ZnO polycrystalline shells, the formation of conducting metallic cores in core@shell nanowires, and nanotrees, and for the solventless surface modification of polymeric coatings and matrixes. We show how the perfluorinated chains grafting of polydimethylsiloxane (PDMS) provides a reliable approach to increasing the hydrophobicity and surface charges at the same time that keeping the PDMS mechanical properties. In this way, we produce efficient Ag/ZnO convoluted piezoelectric nanogenerators supported on flexible substrates and embedded in PDMS compatible with a contact–separation triboelectric architecture. The developed nanomaterials are characterized by XPS, SEM, XRD, and TEM. Thus, factors like crystalline texture, ZnO thickness, nanowires, and nanotrees aspect ratio, and surface chemical modification of the PDMS are explored to optimize the power output of the nanogenerators aimed for harvesting from low-frequency vibrations. Just by manual triggering, the hybrid device can charge a micro capacitor to switch on an array of color LEDs. Outstandingly, this simple three-layer architecture allows for harvesting vibration energy in a wide bandwidth, thus, we show the performance characteristics for frequencies between 1 Hz to 50 Hz and demonstrate the successful activation of the system up to ca. 800 Hz.

4. Piezotronics and piezo-phototronics

When: 2022-06-22, 08:50 - 09:05, Where: Parallel session 3

Bifunctional interfacial engineering for piezo-phototronic enhanced photovoltaic performance of wearable perovskite solar cells

4. Piezotronics and piezo-phototronics

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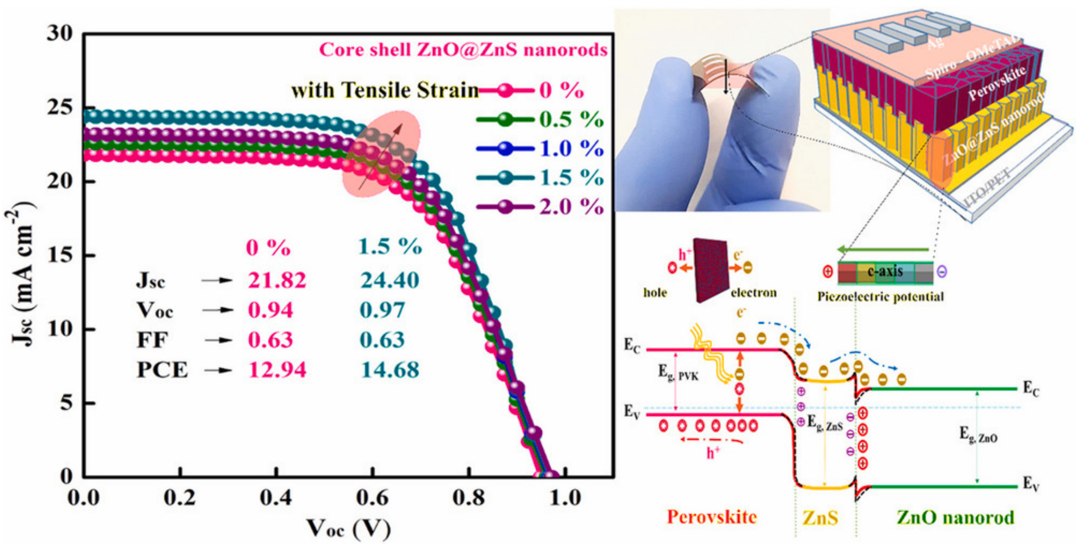
Abstract text: The piezo-phototronic effect can effectively modulate the energy band structure at the interface of p-n or metal-semiconductor junction, manipulating the separation, transport, and recombination of photoinduced charges. While zinc oxide (ZnO) is a good electron transporting layer (ETL), its Lewis's basic nature and presence of surface defects lead to deprotonation of perovskite, resulting in severe degradation of perovskite solar cells (PSC). Herein, the ZnO surface is converted to ZnS, which acts as a bifunctional interfacial layer, passivating the ZnO/perovskite interface by reducing the hydroxyl (–OH) group on the ZnO surface for improved stability and forming strong coordination with Pb^{2+} of perovskite (Zn-S-Pb pathway) and thus adjusting the energy level for efficient electron transport. Consequently, the power conversion efficiency (PCE) of the flexible PSC is remarkably improved from 12.94% to 14.68% under static external strain of 1.5%, ascribed to the strain-induced piezo-polarization charges, which modulate the energy band structure of ZnS/ZnO and ZnS/perovskite interfaces. As a result, spatial separation of photoinduced carriers is facilitated, reducing recombination probability. The energy band diagram is proposed to elucidate the mechanism. This strategy enables effective utilization of the piezo-phototronic effect while enhancing device stability.



When: 2022-06-22, 09:05 - 09:20, Where: Parallel session 3

Bioinspired Intelligent Power Devices

4. Piezotronics and piezo-phototronics

Qilin Hua[1]

[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences

Abstract text: Intelligent power devices are widely used in power solutions ranging from the most basic level of intelligent power control/integration to the most advanced digital control topologies. The power devices used in the conventional sensor-actuator system are commonly operated through a complex series of processes, including analog-to-digital (A/D) or digital-to-analog (D/A) converter, strong and weak electrical isolation, and CPU control. In pace with the advances of artificial intelligence (AI) technology, the power devices that can directly achieve output power modulation responses to external stimuli at a rapid speed are highly desirable for practical use. For instance, in a self-driving car, the output power of the engine needs to be achievable in a rapid self-adjusted response to emergency braking or other accidents. However, the power devices used in AI systems, achieving automated actions and manual manipulation equipment in unexpected environmental changes, is a long-term challenge. Driven by this challenge, people have devoted many efforts to developing new intelligent power devices. Here, under the piezotronic effect, we present bioinspired intelligent power devices with cantilever-structured AlGaN/GaN heterojunctions to demonstrate the output power control in real-time in response to external stimuli (e.g., strain, wind, or magnetic field). Such devices will have great significance in a wide range of AI applications, including autopilot, robotics, and human-machine interfaces.

When: 2022-06-22, 10:25 - 10:40, Where: Parallel session 3

Energy loss of surface plasmon polaritons on silver nanowire waveguides

4. Piezotronics and piezo-phototronics

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Abstract text: Metal nanowires (NWs) can support surface plasmon polaritons (SPPs) propagating beyond diffraction limit, which enables the miniaturizing of optical devices. However, the severe energy losses associated with SPPs propagation have largely hampered their applications in nanophotonic devices and circuits. Developing methods of effectively reducing energy loss is significant and imperative. In this presentation, I will briefly introduce the energy losses of SPPs propagating on Ag nanowires (NWs), and the approaches for reducing energy loss. The energy losses mainly arise from inherent ohmic damping, scattering process, leaky radiation, and absorption of substrate [1]. These processes can be influenced by excitation wavelength, the geometry of NW, and the dielectric environment, especially the effect of substrate. When fabricating SPPs based nanophotonic devices, energy loss induced by the bending part of an Ag NW is critical in affecting its performance [2]. Two-dimensional materials such as graphene have been used to effectively reduce the energy loss of SPPs [3]. Our recent work demonstrates that the propagation loss on an Ag NW placed on Si substrate can be prominently reduced, owing to a stronger interaction between NW plasmons and the Si substrate [4]. These findings are significant not only for developing a convenient and practical way of decreasing energy loss but also crucial for the integration of nanophotonic and electronic circuits on one chip.

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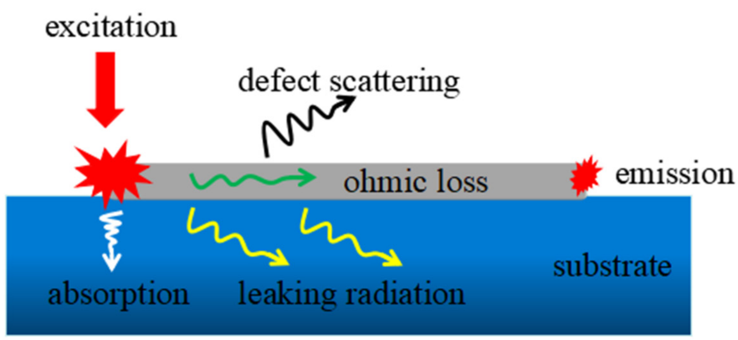

Fig. 1 Propagation losses of SPPs along an Ag NW on substrate.

When: 2022-06-22, 10:40 - 10:55, Where: Parallel session 3

High-performance pyroelectric ceramics for thermal energy harvesting and sensing applications

4. Piezotronics and piezo-phototronics

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Chris Bowen[1]
[1] University of Bath

Abstract text: Pyroelectric materials are able to convert thermal energy into electric energy due to their temperature dependent internal spontaneous polarization and have brought growing interesting in applications ranging from thermal energy harvesting, sensing, imaging and, more recently, electrochemistry. As a result, the development of high-performance pyroelectric materials is crucial for such fields. Herein, lead magnesium niobate-lead antimony-manganese-lead zirconate titanate ($Pb[(Mn_{1/3}Nb_{2/3})_{1/2}(Mn_{1/3}Sb_{2/3})_{1/2}]_{0.04}(Zr_{95}Ti_{5})_{0.96}O_3$, abbreviated as PMN-PMS-PZT) ceramics with high thermal conductivity dopants including AlN and BN were designed to enhance the heat conversion and improve the pyroelectric sensing and energy harvesting properties. Experimental results showed that the ceramics PMN-PMS-PZT with 0.2% AlN and 0.1% BN both presented enhanced thermal conductivity and pyroelectric properties as well as energy harvesting properties which improved by 52.9% and 65.6%, respectively, comparing with the pristine ceramic. From the perspective of electrical generation, PMN-PMS-PZT ceramic with multi-wall carbon nanotubes were constructed to improve the performance figure of merits, which achieved a power of 17.18 μW, 208% increase, compared with the dense ceramic. This work therefore provides a theoretical guidance to design new pyroelectric materials for a variety of applications.

When: 2022-06-22, 12:50 - 13:05, Where: Parallel session 3

Piezotronic readout applied for magnetic field sensors

4. Piezotronics and piezo-phototronics

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Sören Kaps[1], Jürgen Carstensen[1], Rainer Adelung[1]
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Abstract text: Using piezotronic readout and therefore using a piezotronic current to read out a magnetic field sensor is supposed to improve the sensitivity and act as an intrinsic amplifier. [1] Biomedical applications are one of the fields where low sensitivity magnetic field sensors can be utilised. Asymmetrical contacts are used to provide a Schottky contact for the piezotronic effect and an ohmic contact for the highest possible readout. [2]
The presented work gives insight into the underlying processes of the fabrication of contacts to piezotronic material and the application as a magnetic field sensor. With zinc oxide as a model system the contact properties of piezoelectric materials can be further understood. Properties like the number of charge carriers can be tailored by UV-illumination or by changing the surface structure by etching in a flexible manner. [3] By linking this to an equivalent circuit and the electrical and physical properties, further insight into the processes taking place inside the material during current flow was gained.
These strategies can also be applied to magnetic field sensors constructed from a zinc oxide needle as the piezotronic element. Impedance measurements are performed for contact characterisation as well as magnetic sensor characterisation measurements. The magnetic evaluation is done by noise analysis or sensitivity measurements. These measurements are also performed on layered cantilever sensors with aluminum nitride as the piezotronic layer.
The results can be applied for any piezotronics readout and contact production. Additionally, piezotronic current readout might be a chance to improve piezoelectric sensors.

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When: 2022-06-22, 08:25 - 08:50, Where: Parallel session 3

Development and application of dual-mode piezo-gated thin film transistor

4. Piezotronics and piezo-phototronics

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Jit Dutta[1]
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Abstract text: Piezo-gated thin film transistor (PGTFT) capable of modulating charge transport solely relying on piezo-gating effect plays a pivotal role in developing advanced piezotronic devices. However, most PGTFTs were reported to show indistinct piezo-gating effect through piezoelectric-induced modulation of Schottky barrier height in detecting only one-dimensional strain for force sensors. Therefore, we first propose a full-functional PGTFT using ZnO thin film as model piezoelectric semiconducting material that works on dual-mode as depletion and accumulation of charges in detecting strain to exhibit carrier concentration-dependent behavior. Two configurations of the PGTFTs with top and bottom electrodes subjected to external normal forces exhibit opposite force dependence, in agreement with the simulations. With the double electrode PGTFTs, we demonstrate to differentiate normal from bending forces by the patterns of the two IV characteristics. We provide new insights into the piezo-gating effect by the novel ohmic-contact-based PGTFT, which can be operated in dual mode for acquiring more information as the basis of a multi-dimensional piezotronic force sensor.

When: 2022-06-22, 10:00 - 10:25, Where: Parallel session 3

Development and applications of p-n junction nanogenerators: from screening to hybrid energy harvesters

4. Piezotronics and piezo-phototronics

Joe Briscoe[1]
[1] Queen Mary University of London

Abstract text: The interaction between piezoelectric and semiconducting materials, particularly at their interface, leads to a wide range of fascinating behaviours. We have previously demonstrated a novel piezoelectric 'p-n junction' nanogenerator design that used a semiconducting p-type polymer as a contact to the piezoelectric material, rather than an insulator-metal structure [1,2]. I will discuss how the use of this material, and of surface passivation [3], relates to screening at the piezoelectric-contact interface, maximising the power output of a nanoscale piezoelectric material such as ZnO. I will then discuss our research findings that demonstrated how this screening effect could be used positively by embedding ZnO nanorods within a polymer photovoltaic device [4], now commonly referred to as piezo-phototronics. We have since developed this further, building dual-mode 'hybrid' energy harvesters incorporating a piezoelectric nanogenerator with both dye-sensitised and hybrid perovskite photovoltaics. Overall this work demonstrates both the fascinating interactions that occur at piezoelectric-semiconducting interfaces, but also the novel applications that it can enable.

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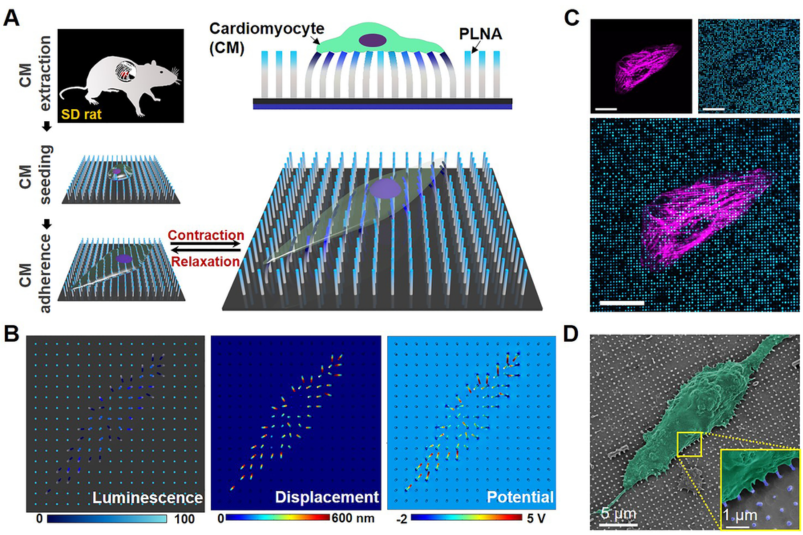
When: 2022-06-22, 08:00 - 08:25, Where: Parallel session 3

High resolution Dynamic Real-time Imaging of Living Cell Traction Force by Piezophototronic effect

4. Piezotronics and piezo-phototronics

Junyi Zhai[1]
Zhou Li[1], Zhong Lin Wang[1]
[1] Beijing Institute of Nanoenergy and Nanosystems, CAS

Abstract text: Dynamic mapping of the cell-generated force of cardiomyocytes will help provide an intrinsic understanding of the heart. However, a real-time, dynamic, and high-resolution mapping of the force distribution across a single living cell remains a challenge. Here a new all-optical stress detection technology has been developed by using strain-sensitive photoluminescence of the third generation of semiconductor quantum wells through the piezo-phototronics. By designing and fabricating a "light nano-antenna" array with all-optical stress detection technology, a spatial resolution of 800 nm and a temporal resolution of 333 ms have been successfully demonstrated for dynamic force mapping of cell force from a live cardiomyocytes by locating the antennas' positions and quantifying the light intensities of the piezo-phototronic light nano-antenna array. This study presents a rapid and ultrahigh-resolution methodology for the fundamental study of cardiomyocyte behavior at the cell or subcellular level. It can provide valuable information about disease detection, drug screening, and tissue engineering for heart-related studies.



When: 2022-06-22, 15:00 - 15:15, Where: Parallel session 3

Self-powered Photodetector for Ultralow Power Density UV Sensing

4. Piezotronics and piezo-phototronics

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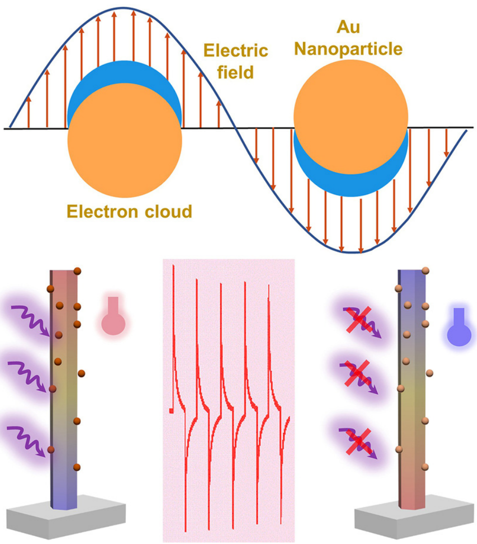
Zhou Li[1]
[1] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences

Abstract text: Ultralow power density UV sensing is crucial to application in military and civilian fields. However, it is still confronted with a low signal-to-noise ratio and long response/recovery time. Here, we report a self-powered photodetector based on the Schottky junction of Au NPs@ZnO NWs, which can detect 325 nm light with the power density of 68 nW/cm², by using pyro-phototronic effect enhanced by localized surface plasmon resonance (LSPR). Under the illumination of 325 nm with the power density of 68 nW/cm², responsivity of photodetector dramatically enhances from 0 to 0.485 mA/W after decorating Au NPs, detectivity is boosted from 0 to 27.49×10^{10} Jones. The responsivity and detectivity of self-powered photodetector show significant enhancement of over 3290% and over 3298% under the illumination of 325 nm light with the power density of 170 nW/cm². The fast recovery ensure detection can be finished within 12 ms. The coupled effect of pyroelectric effect and LSPR provides a guideline to design a high-performance photodetector using other nanomaterials.



When: 2022-06-22, 09:35 - 10:00, Where: Parallel session 3

Piezotronics and piezo-phototronics of hybrid perovskite ferroelectric thin-films for enhanced photoresponse

4. Piezotronics and piezo-phototronics

Jianhua Hao[1]

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Abstract text: Piezoelectric and ferroelectric materials occupy an important position among the family of smart materials. Importantly, piezo-phototronic effect which is three-way coupling among piezoelectricity, photoexcitation, and semiconductor characteristics in the materials gives rise to an effective enhancement of optoelectronic device performance. It is known that hybrid perovskites are very attractive for optoelectronic applications because of their numerous exceptional properties. The emerging perovskite ferroelectric materials have great appeal in the field of piezo-phototronics that enable to effectively improve the performance of optoelectronic devices via modulating the electro-optical processes. In this talk, I will report our recent observation on the piezotronics and piezo-phototronic effect in hybrid perovskite ferroelectric thin-films. High-quality and large-area perovskite films were grown using a diffusion facilitated space-confined growth method. Under external strains, the responsivity of the flexible photodetectors can be modulated by piezo-phototronic effect with a remarkable enhancement enhancement. Our results shed light on the piezo-phototronic devices and offer a promising avenue to broaden functionalities of hybrid perovskite ferroelectrics. It is expected to expand the strategy of modulating optoelectronic behavior by piezo-phototronic effect to other metal-halide perovskite-based optoelectronic devices including solar cells and light-emitting diodes. This work is supported by the Research Grants Council of Hong Kong (PolyU SRFS2122-5S02 and PolyU 153025/19P).

When: 2022-06-22, 12:00 - 12:25, Where: Parallel session 3

Polarization potential on electron and hole transport

4. Piezotronics and piezo-phototronics

Haiyang Zou[1]
[1] Georgia Institute of Technology

Abstract text: Despite recent rapid advances in piezo-phototronic effect on optoelectronics, the fundamental understanding of the polarization potential on electron and hole transport, accounting for many unusual attributes and thus performance in optoelectronic and piezotronic devices, remain comparatively elusive. Herein, we discuss the effect of the polarization potential induced by both strain and the electrical-poling on the photogenerated charge carriers. The photodiode is illuminated with different wavelength lights to selectively choose the photogenerated charge carriers (either electrons or holes) passing through the depletion region, to investigate the piezo-phototronic effect on electron or hole transport separately. This is essential for studying the basic principles in order to develop a full understanding of piezotronics and it also enables the development of the better performance of optoelectronics. And the electrical-poling-promoted polarization potential is reported for rendering hybrid organic-inorganic perovskite photodetectors with high photocurrent and fast response time, displaying a tenfold enhancement in the photocurrent and a twofold decrease in the response time after an external electric field poling. Such electrical-poling-induced polarization potential is responsible for the markedly enhanced photocurrent and largely shortened response time. As such, the utilization of polarization potential at the junctions may represent an important endeavor toward a wide range of high-performance photodetectors, solar cells, transistors, scintillators, etc.

When: 2022-06-22, 12:25 - 12:50, Where: Parallel session 3

Possibilities offered by plasma-based magnetron sputtering processes for the synthesis of functional thin films and surfaces

4. Piezotronics and piezo-phototronics

Stephanos Konstantinidis[1]

[1] Plasma-Surface Interaction Chemistry, University of Mons, Mons, Belgium

Abstract text: Magnetron Sputtering (MS) is a low-pressure plasma-based process. It is a mature, industry-relevant, technique for depositing functional thin films, even on large substrates such as architectural glasses. During MS, plasma ions are accelerated towards the cathode surface by applying an electrical potential. The ion bombardment provokes the ejection of the surface atoms, inducing the so-called sputtering phenomenon. The sputtered atoms condense on the neighboring surfaces and form a film whose thickness can be controlled with nanometer precision.

In this presentation, we will explain what are the "knobs" available to control the plasma characteristics and the way the sputtered atoms condense on the surfaces because this is the key to tailor the physico-chemical characteristics of the thin films. In this respect, MS offers the possibility to design thin film with chemical compositions ranging from pure metals to alloys, from metal oxides to nitrides or carbide compounds, ... Depending on the working parameters, the thin films can be amorphous or (poly)crystalline, porous or dense.
Furthermore, we will present advanced MS processes such as Glancing Angle Deposition (GLAD), which allows controlling the nanostructure of the film with a high-level of precision, and sputtering onto liquids which allows producing colloidal suspensions of nanoparticles.

MS might enable the development of thin film materials relevant in the field of nanogenerators and piezotronics.

When: 2022-06-22, 13:45 - 14:10, Where: Parallel session 3

Theory of Quantum Piezotronics for High Performance Devices

4. Piezotronics and piezo-phototronics

Yan Zhang[1]

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Abstract text: Piezoelectric semiconductors have unique coupling properties of piezoelectric and semiconductor, such as ZnO, GaN, InN and CdS. The new emerging fields of piezotronic and piezophototronic have attracted much attention for flexible energy harvesting and sensor applications[1,2]. For high sensitivity of piezotronic and piezophototronic devices, strain-induced piezoelectric potential plays a key role by controlling carrier generation, transport, and recombination[3-5]. The width of piezoelectric charge distribution is an important parameter for improving performance of piezotronic transistor.

Quantum piezotronics have great potential for designing or improving performances of quantum materials and devices. Recently, Strain-induced piezopotential has been used to tune Rashba spin-orbit interaction (RSOI) in ZnO/P3HT nanowire array structure at room temperature[6].

Spin quantum bit (qubit) plays an important role in quantum information processing and quantum computing. The novel device structures of ultrahigh RSOI induced by the polarization field in ZnO/CdO QWs quantum piezotronic devices[7]. The QW with three layers ZnO and four layers CdO shows a record high RSOI coefficient ~ 83 meV nm assisted by the quantum piezotronic effect, which is around 16.6 times higher than the reported value. Such high RSOI coefficient arises from the combining effect of band inversion and the coupling between the electron and light hole.

The piezotronic transistors based on quantum materials are a new mechanically manipulating devices using by the piezotronic effect[8]. This study can be beneficial to sufficient manipulation of spin qubits by strong RSOI induced by quantum piezotornic effect, and will stimulate an intense researching interest in low-dimensional quantum piezotronic devices for quantum computing.

When: 2022-06-22, 14:35 - 15:00, Where: Parallel session 3

Utilization of Polymer Electrete Layers in Piezotronic Sensors and Energy Harvesting

4. Piezotronics and piezo-phototronics

Rainer Adelung[1]
[1] Kiel University

Abstract text: Energy autonomous sensing including preamplification can be effected by a combination of energy harvesting and sensitive sensor elements. The energy supply for the sensor is the signal that will be detected, in the case presented here, a magnetic field in the lower frequency region [1]. Nanogenerators base on electret layers transduce the magnetic field energy into voltages and currents that can be utilized as input signal for further computing without any additional energy source. Furthermore, a piezotronic read-out eliminates the need for an external pre-amplifier in such a MEMS type magnetic cantilever sensor. The presentation will address the role of electrets in piezotronic and discuss their application to shift the thresholds for amplification like already demonstrated in organic field effect transistors (OFETs) [2]. Even though the concept is already 15 years old it is now yet applied in piezotronic to the best of the authors knowledge. In terms of novel concept, it will be discussed further more how the high voltages and low currents of classical nanogenerators might be transduces by aeromaterials [3] in order to create a powering for, e.g., flow sensors.

[1] M. Mintken, et al., Nanogenerator and piezotronic inspired concepts for energy efficient magnetic field sensors. *Nano Energy* **56**, 420 (2019)

[2] M. Scharnberg et al., Tuning the threshold voltage of organic field-effect transistors by an electret encapsulating layer. *Appl. Phys. Lett*. **90**, 013501 (2007)

[3] F. Schütt et al., Electrically powered repeatable air explosions using microtubular graphene assemblies. *Mater. Today* **48**, 7 (2021).

When: 2022-06-22, 14:10 - 14:35, Where: Parallel session 3

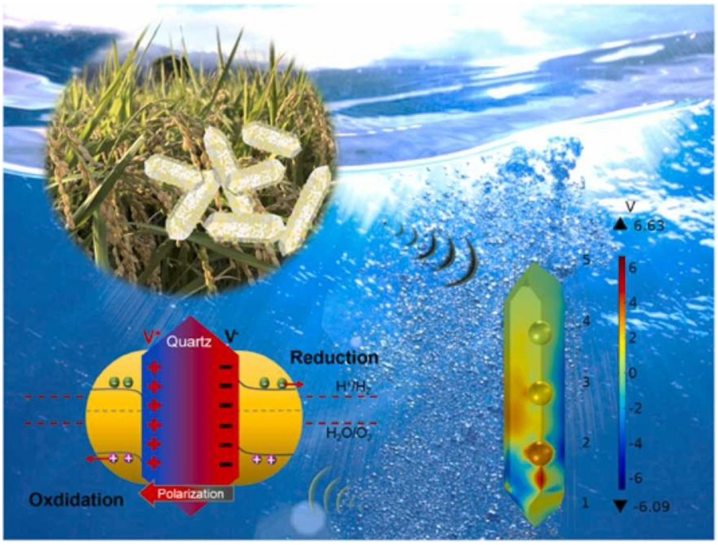
Wireless triboelectric nanogenerator and self-powered photoelectrochemical microsystem through the piezophototronic mechanism

4. Piezotronics and piezo-phototronics

JYH MING WU[1]

[1] National Tsing Hua University, Department of Materials Science and Engineering

Abstract text: We demonstrate the self-powered wireless triboelectric vibration sensor made from the nanoporous SiO2 particles to detect the vibrations and movement in the underwater environment. The nanoporous SiO_2 particles are directly converted from the rice husks (RH_{SiO2}), which exhibit strongly interacting surface hydroxyl groups. Through the enzymatic treatments, the surface potential of the RH_{SiO2} particles can be modulated to obtain either an extremely low or intensely high electronegativity. Specifically, by adding fluorinated groups using fluoroalkylsilane (FOTS) treatment to obtain RH_{SiO2}-F, the charge density of the RH_{SiO2}-F triboelectric nanogenerator (TENG) can be enhanced ~ 56.67-fold as compared to the untreated RH_{SiO2}-TENG. The power density of the RH_{SiO2}-F TENG is increased from 0.077 mWm^{-2} to 261 mWm^{-2}. The RH_{SiO2}-F particles are encapsulated in a quartz cube to fabricate a self-powered wireless sensor that can be stabilized for operating in an underwater environment at various temperatures. The theoretical calculation further demonstrates that the triboelectric potential is dramatically established between the surface-functionalized RH_{SiO2}-F particles and the quartz's surface. With porous nature of rice husks covered with nano-Si is of a high functionality for designing a new-type TENG which has a great potential to apply in environmental monitoring. In addition, self-powered photoelectrochemical quartz microrods made from rice husks and hybrid with TiO2 nanodots to form a microsystem for the degradation of dye molecules and hydrogen production through the piezophototronics process also be reported.



When: 2022-06-22, 13:05 - 13:20, Where: Parallel session 3

Super-resoluiton detection and imaging based on micro-/nanophotonics

4. Piezotronics and piezo-phototronics

Qing Yang[1, 2, 3]
Zhong Wen[2], Xiaowei Liu[1], Chenlei Pang[1], Mingwei Tang[1], Qianwei Zhang[2], Muchun Lin[2], Qilin Deng[2], Xu Liu[1, 2, 3]
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[2] State Key Laboratory of Modern Optical Instrumentation, College of Optical Science and Engineering, Zhejiang University,Joint International Research Laboratory of Photonics, Hangzhou, 310027, China
[3] Collaborative Innovation Center of Extreme Optics, Shanxi University, Taiyuan, 030006, China

Abstract text: Breaking through the diffraction limit of linear systems and realizing universal high-throughput and high-stability super-resolution imaging is an urgent problem to be solved to promote the in vivo/online application of super-resolution. Based on the new idea of spatial spectrum engineering, we proposed a novel mechanism of full-vector-tunable deep spatial frequency shift mechanism, by which the theoretical limitation on the resolution of a linear optical system has been overcome, the space bandwidth product of the microscope system has been increased by 2 orders of magnitude, the high-throughput super-resolution imaging compatible with both labeled and label-free has been realized . The optical field modulation based on frequency-mixing and dual event control mechanism has been proposed, which overcomes the problem of in-body stable imaging, improves the tracking speed by 4 orders of magnitude, and realizes three-dimensional (3D) high-stability and high-resolution imaging under the motion of long optical fibers. A new technology of light field coding in spatial spectral domain has been developed, low-crosstalk and ultra-wideband spatial spectral information has been obtained, high-performance super-resolution imaging chips and endoscopy systems has been realized. The high-throughput super-resolution microscopic detection equipment in vivo/online has been independently researched and developed, promoting its application in production lines and clinic. Multi-functional super-resolution 3D endoscopy imaging for complex objects in the lumen will be explored in the future.

Poster

1. Triboelectric nanogenerators

When: 2022-06-20, 11:07 - 11:14, Where: Poster session

A study of triboelectric charge behavior through the cryogenic triboelectric measurement

1.1 Fundamentals
1. Triboelectric nanogenerators

Da Woon Jin[1]
Jong Hoon Jung[1]
[1] Department of Physics, Inha University, Incheon 22212, Republic of Korea

Abstract text: In recent years, many studies about contact electrification have been conducted to know about the origin of the triboelectric phenomenon. Various models have been reported to explain the triboelectric effect, but still not clear. When the triboelectric charge transfers from one contacting material to another material, it is considered to be either electrons, ions, or materials. However, in many cases, determining the exact transferred charge carrier is complex and ambiguous. Therefore, in order to understand the triboelectric effect exactly, it is necessary to study the triboelectric charge transfer. Measuring the temperature dependence of the triboelectric effect can provide information on the temperature-dependent triboelectric charge behavior, and it will be very helpful for understanding the mechanism of the triboelectric effect.

In the present work, we have set up a cryogenic measuring system and measured the temperature-dependent triboelectric effect. The system is made by integrating Physical Property Measurement System (PPMS) and a customized linear motor. Using the customized system, we measured the triboelectric charge developed between Al electrode and the three commercial polymers (Polytetrafluoroethylene (PTFE), Polyimide (PI), Polypropylene (PP)) at 20 ~ 350 K and in vacuum (10^{-5} Torr) environment, when they come into contact. When the temperature was cooled down, the amount of generated charge was enhanced. These results are inconsistent with the other previous studies. Our results can help to understand the charge transfer mechanism and contribute to improving the performance of the triboelectric nanogenerator (TENG)

When: 2022-06-21, 11:48 - 12:00, Where: Poster session

Application of cellulosic materials in triboelectric nanogenerators for a completely biodegradable TENG

1.1 Fundamentals

1. Triboelectric nanogenerators

Haider Iftikhar[1]

Maryam Borghei[1], Alireza Eivazi[2], Christina Dahlström[2], Magnus Norgren[2], Orlando Rojas[1, 3]

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[2] FSCN research center, Mid Sweden University, Sundsvall, Sweden

[3] Chemical and Biological Engineering, University of British Columbia, Vancouver, Canada

Abstract text: Our fast-paced technology centric world, driven with the high consumption of electrical energy, has necessitated in the requirement for alternative energy harvesting. This has led to various innovative techniques, especially which ceases the need of fossil-based fuels, toxic chemicals and rare earth metals that are extremely costly and detrimental to the environment. Triboelectric nanogenerators (TENG) are one such category of devices that inherently do not require any fuel or toxic chemicals to produce continuous electrical energy. To alleviate their level in environmental friendliness and recyclability, application of cellulosic material has been investigated to be especially effective and efficient with respect to tribo-charging. In this poster we demonstrate the successful application of tempo oxidized cellulose nano fibers (TOCNF) as a positive tribo-material and cellulose acetate (CA) as a negative tribo-material to produce a greener alternative for higher performance polymeric materials used contemporarily in TENGs at large. Our emphasis lies on the high performance of cellulosic material rivaling other polymeric materials that are neither biodegradable nor recyclable. For this we have especially applied cellulose acetate as a biodegradable alternative to Teflon (PTFE) which is toxic and extremely harmful to the environment.

When: 2022-06-21, 11:06 - 11:12, Where: Poster session

Control of the triboelectric charge density of cellulose nanofibrils by chemically tailored molecular surface modification

1.1 Fundamentals

1. Triboelectric nanogenerators

Yanhua Liu[1]

Shuangxi Nie[1]

[1] School of Light Industry and Food Engineering, Guangxi University, Nanning 530004, PR China

Abstract text: Studying the charge density of materials is of great significance for deepening the understanding contact electrification. However, the effect of the material surface charge on contact electrification has not been elucidated in detail. The surface composition of the material is one of the key factors affecting the charge density. In this work, silane coupling agents with the same main chain but different terminal functional groups were selected to tailor cellulose nanofibrils, and the relationship between charge density and contact electrification was studied. The results show that charge density of cellulose nanofibrils can be altered by introducing functional groups with different electron-withdrawing or electron-donating abilities to its surface. Thanks to the regulation of the number and density of functional groups, the range of the charge density can be tailored more specifically. More importantly, a relatively systematic and improved mechanism is proposed to clarify the influence of chemically tailored surfaces on charge density. This article provides guidance for the systematic study of chemically tailored molecular surface modification to control triboelectric charge density.

When: 2022-06-22, 11:00 - 11:07, Where: Poster session

Exploring the behavior of frictional heat along with material transfer during friction through real-time measurement

1.1 Fundamentals
1. Triboelectric nanogenerators

Dong Woo Lee[1]
Dae Sol Kong[1], Jong Hoon Jung[1]
[1] Department of Physics, Inha University

Abstract text: Since it was first proposed, triboelectric nanogenerators (TENGs) has continued research and has proven that it is a suitable technology for use as a self-powered sensor and wearable device. In order to utilize it more efficiently than before, it is necessary to understand the fundamental mechanism, and the key issues are the identity of charge carriers and the transfer mechanism between each contact material. A small number of in-operando experiments, such as experiments using ultraviolet irradiation or photoelectron spectroscopy during contact electrification, have been reported. However, frictional heat inevitably appears when friction occurs, and in-operando experiments on temperature were rarely reported. To clarify the mechanism of contact electrification, measurement and control can be systematically performed, and measurements must be made during friction (in-operando).

A sliding friction method between FTO and PDMS material was used, and the degree of crosslinking of PDMS was compared, and surface temperature measurement was performed during contact electrification. According to the degree of crosslinking, the temperature change and the amount of frictional charge showed opposite tendencies. The Young's modulus and coefficient of friction change greatly depending on the degree of crosslinking, and the thermal conductivity and specific heat less change. With XPS data that transfer of a part of PDMS to opposite side FTO surface according to friction time, these results should be that partial frictional heat was used for the rupture and creation of bonds during the sliding.

When: 2022-06-21, 11:12 - 11:18, Where: Poster session

Peeled-off polydimethylsiloxane film-based triboelectric nanogenerator for understanding the mechanism of triboelectrification

1.1 Fundamentals
1. Triboelectric nanogenerators

Huidrom Hemojit Singh[1]
Da Woon Jin[1], Jong Hoon Jung[1]
[1] Department of Physics, Inha University, Incheon 22212, Republic of Korea

Abstract text: The triboelectric nanogenerator (TENG) operates based on the triboelectrification and electrostatic induction principles. Although electrostatic induction is a well-known phenomenon in the scientific community, the triboelectric effect is still poorly understood. Understanding this physical phenomenon is critical for proposing a correct mechanism and improving TENG's performance.
In the present work, we have fabricated single electrode TENG out of peeled-off polydimethylsiloxane (PDMS) films to better understand the phenomenon of triboelectrification. PDMS films were prepared on ITO-Glass and ITO-PET substrates. Despite the fact that the two surfaces have similar surface roughness and surface energy (32-40 mN/m), the PDMS film peeled-off from the ITO-Glass substrate produces more TENG output than the one removed from the ITO-PET substrate. The increase in surface energy of PDMS peeled off from ITO-Glass is confirmed by electrostatic force microscopy, and the XPS result shows more materials being transferred. It has been concluded that the enhancement in material transfer is dependent on the substrate's surface energy and the difference in Young's modulus between the two contacting materials. The current work not only validates the material transfer phenomenon that control triboelectrification, but it also proposes a novel strategy for increasing TENG's output.

When: 2022-06-20, 11:21 - 11:28, Where: Poster session

Role of elastic modulus in triboelectrification of identical P(VDF-TrFE) polymers

1.1 Fundamentals

1. Triboelectric nanogenerators

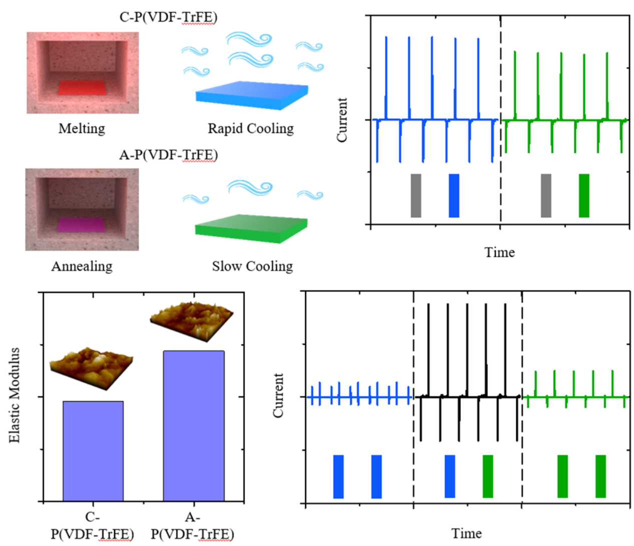
Dong Geun Jeong

Young Joon Ko[1], Jong Hoon Jung[1]

[1] Department of Physics, Inha University, Incheon 22212, Republic of Korea

Abstract text: While the triboelectric nanogenerators have demonstrated the high conversion efciency of mechanical vibrations into electricity, there are several unsolved fundamental issues in contact electrifcation. One of the most puzzling issues is that contact electrifcation occurs even with two identical materials. To explain this intriguing behaviors, several models are proposed, such as mosaic charge distribution, local temperature differences, and macromolecular interactions.

Here, we report an intriguing triboelectrification behavior of thermally treated P(VDF-TrFE) polymers. Cooled (C-) and annealed (A-) P(VDF-TrFE) films were prepared by the rapid cooling of the melt solution and the subsequent annealing, respectively. The C-P(VDF-TrFE) had sparse grains and small elastic modulus and surface charge density, while, the A-P(VDF-TrFE) had dense grains and large elastic modulus and surface charge density. When the polymers contacted ITO electrodes, the triboelectric outputs of C-(PVDF-TrFE) were larger than those of A-P(VDF-TrFE). When the polymers contacted each other, the triboelectric outputs of different P(VDF-TrFE) films were significantly larger than those of similar P(VDF-TrFE) films. Based on detailed X-ray photoemission spectroscopy results, we suggested that roughness-induced frictional heat and elastic modulus differences may play an important role in minute material and/or ion transfer during the triboelectrification of identical P(VDF-TrFE) polymers.



When: 2022-06-21, 11:18 - 11:24, Where: Poster session

Autonomous interacting triboelectric system for simultaneous water harvesting and power generation

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Song Zhang[1]
shuangfei wang[1], shuangxi nie[1]
[1] School of Light Industry and Food Engineering, Guangxi University, Nanning 530004, PR China

Abstract text: Water and energy are intimately intertwined, and it is high time to put forth integrated approaches to address the challenges and opportunities of the water-energy nexus. Herein, a novel droplet triboelectric nanogenerator (DENG) was developed by coating a layer of hydrophilic cellulose ester on PTFE array inspired from cactus followed by adhesion of copper. The collection of fog relies on the synergistic effect of the hydrophilic components of cellulose esters and biomimetic structures. When the hydrophilic area reached 6.2 mm^2, the device presented a highwater collection rate of about 4663 mg cm^{-2} h^{-1}. In addition, the droplet generator converted the mechanical energy of the condensed droplets into electrical energy using the volume effect, achieving excellent electrical output and even lighting 200 LED lamps

When: 2022-06-22, 11:42 - 11:49, Where: Poster session

Enhancing the Charge Density of Triboelectric Nanogenerator via Charge Traps from Photon-Generated Carriers

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Fayang Wang[1]

Xin Chen[1], Peng fan Wu[1], Daqiao Tong[1], Yanjun Zhao[1], Xiaojing Mu[1]

[1] Key Laboratory of Optoelectronic Technology & Systems Ministry of Education, International R & D center of Micro-nano Systems and New Materials Technology, Chongqing University, Chongqing 400044, PR China

Abstract text: The output performance of triboelectric nanogenerator (TENG) is an important candidate to be considered for energy supply to the sensor nodes. The previous works have focused on high dielectric particle doping, and the output performance of TENG is limited. Herein, a new strategy is creatively proposed based on charge traps from photon-generated carriers, which are acquired from the composites TiO_2/MXene, to further promote the output performance of TENG. The high dielectric properties of the composites first result in the improvement of the output performance of TENG, and then photon-generated carriers effect enables composites which are doped into tribo-material, further enhance the output performance. As the photon-generated electron–hole pairs produced by TiO_2 have a high recombination rate and small specific surface area, the MXene are chosen to combine with the TiO_2 and form a heterojunction at the point of interface contact which lead to more charge traps. A sustainable and enhanced output performance of about 63 μA (short-circuit current) and 355 V (open-circuit voltage) are produced via photon-generated carriers for the boosted TENG with the doping content of 0.1wt%, and it delivers a peak output power of 11.23mW with an impedance of 1 MΩ, which is giving over 2.9-fold enhancement in output power compared with the traditional TENG with PDMS(3.91mW). This work provides a profound understanding of the working mechanism of photon-generated carriers effects for boosting the output performance of TENG, and it’s indeed an effective way for promoting TENG’s output.

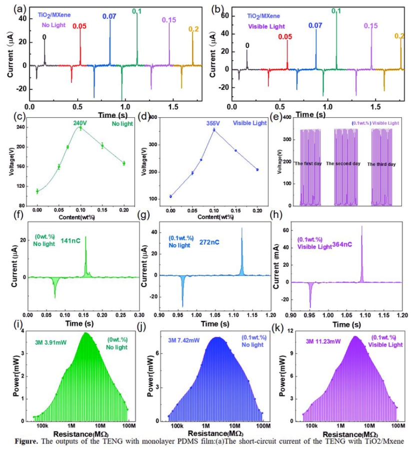
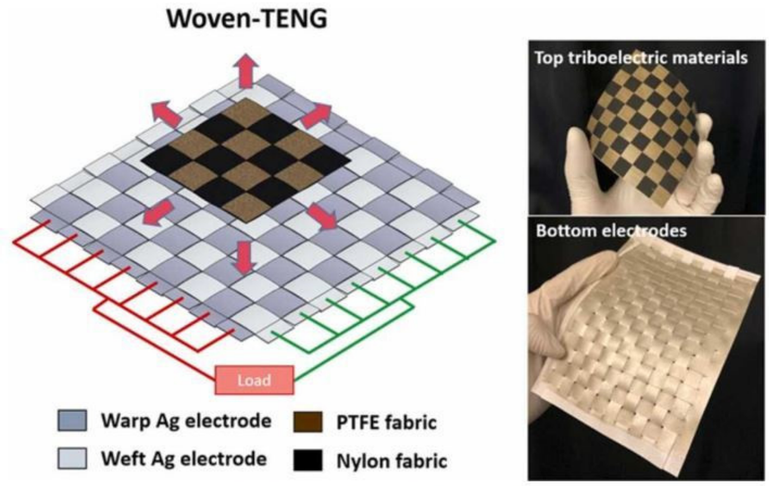


Figure. The outputs of the TENG with monolayer PDMS film:(a)The short-circuit current of the TENG with TiO2/Mxene composites;(b)The short-circuit current of the TENGs with TiO2/Mxene composites under the 0.6 times visible light irradiation;(c)The open-circuit voltage of the TENG with TiO2/Mxene composites;(d) The open-circuit voltage of the TENG with TiO2/Mxene composites under the 0.6 times visible light irradiation;(e)Stability test of the TENG with TiO2/Mxene composites under the 0.6 times visible light irradiation;(f-h)The effect of light on the transferred charge quantities;(i-k)The output power of the TENG with TiO2/MXene composites



https://doi.org/10.1016/j.nanoen.2021.106739

When: 2022-06-21, 11:30 - 11:36, Where: Poster session

Polarity controlled and soft triggered highly durable direct current triboelectric Nanogenerator

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Jae Yeon Han[1]
Huidrom Hemojit Singh[1], Jong Hoon Jung[1]
[1] Department of Physics, Inha University, Incheon 22212, Republic of Korea

Abstract text: Among the different modes of operation of triboelectric nanogenerators (TENGs), the sliding mode of TENG is considered to be the most efficient and gives the highest output. However, in this mode, as the surface of the contacting materials slide between each other, it has a serious wear problem which results in a sharply decrease in their performance after some time. Furthermore, because the electric output is alternating current (AC), a rectifier is required to feed the output to any other electronic device, which further decreases its efficiency.

Here, we designed and fabricated a polarity-controlled and soft-triggered (P-S) TENG. The present device is highly efficient and gives durable direct-current (DC) output. The device was fabricated by using polytetrafluoroethylene (PTFE), nylon, and Cu films for triboelectrification, while another set of Cu films was employed for collecting the charges. The device consists of two acrylic cylinders, which give mechanical support to the rotating TENG. To generate DC output, the triboelectric materials i.e., PTFE and nylon, were fixed alternately to an acrylic cylinder with four copper patches attached to the inner acrylic cylinder. We optimized the dimensions of the contacting materials, segmentation of contacting coppers and even performed corona treatment to get maximum output from the device. The device gives an open-circuit voltage of 620 V with a short circuit current of 14 μA. The present work presents a novel strategy for generating a highly durable DC output in rotating TENG.

When: 2022-06-21, 11:36 - 11:42, Where: Poster session

Porous PDMS conformable coating for high power output carbon fibers-based single electrode triboelectric energy harvesters

1.2 Micro-nano-power sources

1. Triboelectric nanogenerators

Raquel Barras[1]

Andreia dos Santos[1, 2], Elvira Fortunato[1], Rodrigo Martins[1], Hugo Águas[1], Rui Igreja[1], Pedro Barquinha[1], Luís Pereira[1, 2]

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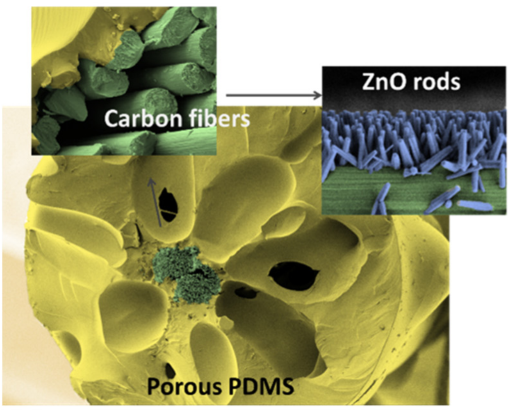
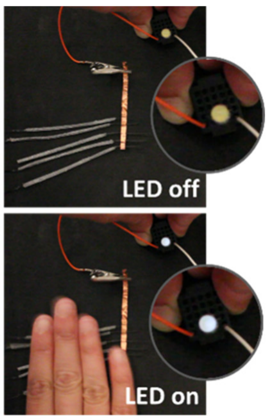
Abstract text: A new method for depositing PDMS directly onto conductive carbon yarns is proposed to produce Triboelectric Generator Yarns (TEG yarns). The in-situ PDMS curing method described in this study allows the fast formation of a uniform thick coating over conductive surfaces regardless of their roughness. Single-electrode configuration TEG yarns are developed and their electrical output is optimized by precisely adjusting the PDMS layer thickness and by changing the chemical and physical nature of the carbon fiber (CF) yarns' surface. Functionalizing the CF yarns' surface with ZnO rods combined with porous PDMS coating can enhance their electrical output. The best results achieved using this type of TENG yarns with an average diameter of 1.74 mm, which can be obtained after only 3 min of PMDS deposition by "*in-situ*" curing method. A maximum of 72 V peak-to-peak and 10 μA (74.1 μW cm^{-2} of power density with a load resistance of 20 MΩ) is reached when applying an impact force of 600 N to a set of five TENG yarns connected in parallel. The output is stable even after 10,000 cycles and this set of TENG yarns is also able to light at least 28 LEDs when tapping by hand, proving a contribute towards the development of basic building blocks to power the future generation of wearables. In addition, electrophoretic deposition of nanocrystalline cellulose films on enhancing TEGs electrical output was also studied. A quantification of both tribo and piezoelectric phenomenon contribution for the final output was estimated.





When: 2022-06-20, 11:35 - 11:42, Where: Poster session

Switchable power generation in triboelectric nanogenerator enabled by controlled electrostatic discharge

1.2 Micro-nano-power sources
1. Triboelectric nanogenerators

Jiaming Zhou[1]
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Abstract text: Since the concept of triboelectric nanogenerator (TENG) was proposed in 2012, it has been applied to a wide range of fields as a promising energy harvesting technology. TENG converts environmental mechanical energy into electrical energy by utilizing contact electrification and electrostatic induction. Harvesting the hydrodynamic energy in raindrops is an efficient way to meet the growing energy demands. However, the electricity generated by conventional droplet-based TENGs is pulsed alternating current (AC), which cannot be directly used as a power source. The rectifier bridge or the power management circuits used to transfer AC into direct current (DC) will greatly reduce the portability of TENG. Here, we report a droplet-based direct current triboelectric nanogenerator (DDC-TENG) without using any rectifiers. Based on the dielectric breakdown mechanism, a small gap is designed between the triboelectric layer and the electrode. Using the small gap, this sandwich structure single electrode mode DDC-TENG can generate a unidirectional voltage (maximum 2.5V) and transferred charge (maximum 0.63nC) in the periodic motion of droplets. This new design provides a way to harvest the micromechanical energy of water droplets and directly use them in devices.

When: 2022-06-20, 11:49 - 12:00, Where: Poster session

A self-powered gas sensors system based on conductive wood for food-quality assessment

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: A self-powered triboelectric nanogenerator (TENG)-based wireless gas sensor system (TWGSS) is presented to realize selective, sensitive, and real-time wireless food-quality assessment in a cold-supply chain. TWGSS can real-time monitor the key food spoilage markers gas (e.g., ammonia) and maintain excellent stability under high humidity (75%) and low temperature (-18 °C). Benefiting from the three-dimensional porous structure of wood and ammonia sensitive properties of the carbon nanotubes materials, output voltage of the TENG selectively decreases with the increase of ammonia concentrations from 50 to 500 ppm. Moreover, the TENG exhibits an ammonia-sensing response of 0.85 at 500 ppm ammonia, which is much higher than the other common gases released from perishable foods under the same gas concentrations. Through system integration and power management, a self-powered triboelectrically driven system that can also be used as a gas sensor and wirelessly transmit data to the user interfaces. This work provides a design concept for the application area of the TENGs to the assessment of food quality, and also promotes the development of self-powered systems in food industry.

When: 2022-06-20, 11:00 - 11:07, Where: Poster session

A self-powered signal rope based on triboelectric nanogenerator towards diving safety

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: In this work, a novel mechanical device is designed for diver's signal rope. By combining the mechanical structure with a triboelectric based sensor. The mechanical movement of the rope pulling can be converted into the electrical signal through the Triboelectric Nanogenerator(TENG). The mechanical structure is composed of a lever and a compressing spring. One end of the lever moves down as pulling the signal rope. The other end of the lever is raised at the same time resulting in the contact with the TENG. The copper and PTFE film contact with each other under the hit of lever. The positive and negative charge are induced respectively due to the electro-negativity difference between the PTFE and copper. As releasing the diver rope, triboelectric electrons flow from the upper copper electrode to the lower one through the external circuit, and a electrical signal is generated. Then as the two layers contacted again, the electrons flow back to the upper electrode again. The effect of some main structure parameters on the electrical performance of TENG are studied including the constant stiffness of compression spring, the position of pivot. Through the theoretical analysis and experiment, we find the voltage output of the device increases linearly with the pulling force. Finally, the electrical signal is processing by the machine learning. We believe our work provides a new way to ensure the safety of diver and improve the intelligence of diving equipment.

When: 2022-06-20, 11:14 - 11:21, Where: Poster session

Advantageous utilization of triboelectric effect based electric signal generation in engineering fields

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Triboelectric signal generation is highlighted as a novel mechanism for development of various types of energy harvesters as well as self-powered sensors. Unlike most of the regarding research as materials and chemistry oriented approaches, the role of the classical mechanics in aforementioned triboelectric signal generation is introduced. By adopting the ordinary power transmission unit into the triboelectricity based energy harvester, called triboelectric nanogenerator (TENG), the output performance can be significantly increased and such remarkable increase allows us to use the triboelectric signal generation mechanism more practically. As one of the representative examples, the effective biomechanical energy harvesting via triboelectric signal generation is introduced. Along with it, the advantageous effect of the triboelectric signal generation on the operation of the classical mechanical elements, which are frequently employed for direct power transmission, is proposed. In this regard, the self-triggered mechanical sensors, which enable us to inform various characteristics of the machine components, are proposed. Since the electric signal can be generated without any other external power sources, the present sensor can be considered as self-triggered. Gear and brake are one of the most ordinary and effective components for transmitting mechanical power as a core component of machines. Given that the operation of the gear and brake in power transmission is based on sequential contact and separation between two separated components, the simple modification of the outermost surface of the conventional machine components enables us to spontaneously generate triboelectric signal during ordinary power transmission.

When: 2022-06-21, 11:00 - 11:06, Where: Poster session

Aramid nanofiber aerogel-based Triboelectric Nanogenerator for enhanced output in harsh environments

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Triboelectric nanogenerators (TENGs) have aroused great concerned in terms of addressing the energy supply required for the applications in distributed, mobile, disordered, and wired/wireless sites. It is widely used in artificial intelligence, flexible wearable and other fields in recent years. The reasonable electron-acceptor layer in the triboelectric layer can significantly improve the output of TENG. In this study, the electron storage layer was successfully constructed in the aramid aerogels by regulating the orientation of CNT. The results show that CNT has the highest output performance when it is parallel to the bottom surface, with an open circuit voltage of 140 V and an output charge of 40 nC, which may be attributed to the formation of numerous micro-capacitors in the aerogel. In addition, the stability of TENG output at high temperature was investigated by placing TENG at 200 °C. The experimental results show that CNT/aramid nanofiber (ANF) aerogels can still maintain 50% charge after 2 hours. Finally, the mechanism of improving output and stability of CNT electron acceptor layer at high temperature is discussed. By embedding CNT electron acceptor layer into the ANF aerogel, the electron retention ability significantly increased, which provides an effective strategy for improving the output performance of TENG at high temperature.

When: 2022-06-21, 11:42 - 11:48, Where: Poster session

Bioinspired Soft Electroreceptors for Artificial Pre-Contact Somatosensation

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Hai Lu Wang[1], Jiajia Shao[1], Xiong Pu[1], Zhong Lin Wang[1]
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Abstract text: Artificial haptic sensors form the basis of touch-based human-interfaced applications, which, however, are unable to respond to remote events before physical contact. Some elasmobranch fishes, such as sharks in seawater, employ electroreception somatosensory system for remote environmental perception. As inspired by this ability, we design a soft artificial electroreceptor for sensing approaching targets. The electroreceptor, enabled by an elastomeric electret, is capable of encoding environmental pre-contact information into a series of voltage pulses. Our artificial electroreceptors can function as unique pre-contact human interfaces, as demonstrated through applications in pre-warning system, robotic control, game operation and 3D object recognition. These superior capabilities in perceiving proximal pre-contact events can largely enrich the functionalities and applications of human-interfaced electronics.

When: 2022-06-22, 11:49 - 12:00, Where: Poster session

Development and Application of Triboelectric Sensors in the Industrial Technology

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: With the increasing demand for high mobility, wide distribution, and wireless operation of modern sensors, it is inevitable to develop new self-powered smart sensing technologies. Therefore, a self-powered sensing method for the modern industry has been proposed. In particular, a series of triboelectric sensors are designed for the common mechanical motion sensing and fluid state monitoring requirements. For the industrial technical requirements, a series of triboelectric mechanical motion sensors, such as a linear motion triboelectric position sensor, a highly integrated triboelectric smart bearing, a triboelectric rotary motion sensor, are proposed for speed detection, real-time direction monitoring. The sensors have realized the intelligent, flexible design and low-cost manufacturing of mechanical equipment motion sensing. Besides, for the fluid measurement, a novel wave coupling method is first proposed, which reveals that liquid-solid electrification realizes flow sensing. Simultaneously, a series of triboelectric flow sensors with a built-in float structure that can be used for gas or liquid measurement are invented. The comparison verifies that its output performance is identical with that of commercial sensors. In addition, the vibration sensor is one of the most widely applied sensing technologies. Our team proposes a novel double-spring-piece structured triboelectric sensor for broadband vibration real-time monitoring and warning. The sensor can achieve vibration frequency measurement in the range of 0~200 Hz with high linearity, and the error rate is less than 0.015%. The above work can effectively promote the application and development of self-driving sensing technology in the field of smart machinery sensing.

When: 2022-06-22, 11:07 - 11:14, Where: Poster session

Flexible Textile Direct-Current Generator Based on the Tribovoltaic Effect at Dynamic Metal-Semiconducting Polymer Interfaces

1.3 Self-powered sensors and devices
1. Triboelectric nanogenerators

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Abstract text: Generation of direct current (DC) from mechanical kinetic energies is crucial for realizing self-powered wearable electronics. Here, we report a flexible textile-based DC generator based on the tribovoltaic effect at a dynamic metal-semiconducting polymer interface. The tribovoltaic effect refers to a phenomenon in which an energy “quantum” is released once an atom-atom bond is formed at the dynamic interface of two contacting materials; such released “binding” energy excites electron−hole pairs at metal-semiconductor interfaces or semiconductor−semiconductor pn junctions. This textile DC generator, based on the dynamic Schottky junction between an Al slider and a poly(3,4-ethylenedioxythiophene)-coated textile, can output a voltage of approximately 0.45−0.70 V. The voltage and current can be increased by simply connecting multiple generators in series or in parallel. Seven generators in series can power an electronic watch constantly without any conditioning circuit. These findings offer an efficient strategy for harvesting mechanical energies and realizing self-powered electronics.

When: 2022-06-22, 11:14 - 11:21, Where: Poster session

Highly Sensitive Self-powered Pressure Sensors over a Wide Pressure Range Enabled by Tailoring Free Volume of Cellulosic Triboelectric Materials

1.3 Self-powered sensors and devices

1. Triboelectric nanogenerators

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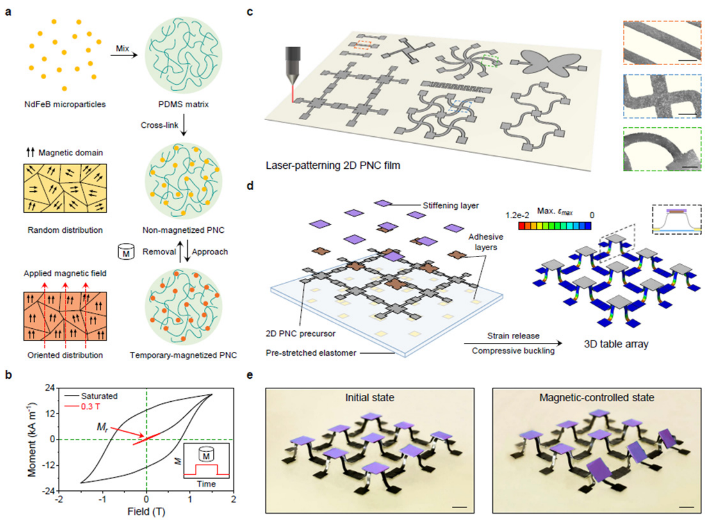
Abstract text: The next generation of sensors should be self-powered, maintenance-free, precise, and have wide-ranging sensing abilities. Extensive research and development in the field of self-powered pressure sensors, however, most of the researches focus on developing triboelectric materials with surface structures, and such strategies are only effective in improving the sensitivity in the low-pressure range (e.g., up to 10 kPa), so they cannot achieve wide-range pressure detection with high sensitivity. To overcome this well-known obstacle, in this paper, a cellulose paper based on free volume regulation is designed, which is used as a triboelectric material-assembled triboelectric nanogenerator for a pressure sensor, which can detect the pressure in the range of 0.5 ~ 1000 kPa, and the whole range with high sensitivity. In addition, the dielectric properties of cellulose paper are significantly improved through the free volume control method, which further greatly improves the triboelectric property of cellulose paper. This achievement facilitates wide-range pressure detection for a broad spectrum of applications, ranging from simple human touch, sensor networks, smart robotics, and sports applications, thus paving the way forward for the realization of next-generation sensing devices.



When: 2022-06-20, 11:42 - 11:49, Where: Poster session

A superhydrophobic cellulose based triboelectric material for liquid energy harvesting

1.4 Blue energy
1. Triboelectric nanogenerators

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Abstract text: Cellulose is the most abundant natural polymer on earth. Because it is renewable, biodegradable, and biocompatible, it offers distinct advantages as a starting material for bio-based triboelectric nanogenerator (bio-TENG). However, weak polarity, poor hydrophobicity, and insufficient functionalization on the natural cellulose surface severely limit the development of cellulose on liquid-solid triboelectric nanogenerator (L-S TENG) for liquid energy harvesting. In this work, chemical functionalization is employed to control the surface polarizability and hydrophobicity of cellulose nanofibrils (CNFs) to obtain a cellulose based L-S TENG. Functional groups on the CNF surface are modified with triethoxy-1H,1H,2H,2H-tridecafluoro-n-octylsilane (PFOTES) in a straightforward and facile process. Fluorine-bearing silane chains are grafted to the surface of CNFs, which increases their triboelectric charge density and improves their hydrophobicity. Triboelectrification energy can be captured and released when droplets are colliding or slipping on the superhydrophobic layer. The superhydrophobic cellulose based L-S TENG show the excellent output performance and stability. This research advances the application of cellulose materials in liquid energy harvesting, and also expands the selection of solid triboelectric materials for L-S TENG.

2. Piezoelectric nanogenerators

3D-Printed Stacked Ionic Assemblies for Iontronic Touch Sensors

2.1 Fundamentals

2. Piezoelectric nanogenerators

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Abstract text: Sensing is the process of detecting and monitoring physico-chemical environmental parameters. Herein, brand-new iontronic sensors, which utilize touch-induced ionic charge separation in ionically conductive hydrogels, are introduced for use in object mapping, recognition and localization. This is accomplished using high resolution stereolithography 3D printing of stacked ionic assemblies consisting of discrete compartments having different transport properties. The latter assemblies readily allow programming directional sensing response with output signal amplification/attenuation by means of variations in ion type, charge density and crosslinking density within the iontronic device. While the output voltages is consistent with movement of the mobile counterions away from the indented region, the generated output voltage amplitude at a given applied force is found to be approximately proportional to the hydrogel charge density and inversely proportional to the hydrogel crosslinking density. The resulting tactile sensors also exhibit sensitive touch-pressure monitoring and localization for activity recognition applications, simplifying the relevant sensing systems and favoring integration. In addition, we propose a fundamental understanding aiming at elucidating the underlying mechanism behind iontronic touch sensors. The entire electromechanical response is therein consistent with a streaming potential model, while the initial, small strain response can also be described using a Nernst-Donnan model.

When: 2022-06-21, 11:24 - 11:30, Where: Poster session

Porous ZnO thin films on paper substrates for the development of piezoelectric nanogenerators and self-powered sensors

2.3 Self-powered sensors and devices
2. Piezoelectric nanogenerators

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Abstract text: In this communication, we demonstrate a plasma synthesis approach for the fabrication of piezoelectric nanogenerators and self-powered sensors on paper-based substrates. Polycrystalline ZnO nanocolumnar thin films are deposited by plasma enhanced chemical vapor deposition on common paper supports using a microwave electron cyclotron resonance reactor working at room temperature and yielding high growth rates. Applying Kinetic Monte Carlo simulation tools, we elucidate the basic shadowing mechanism behind the characteristic microstructure and porosity of the ZnO thin films. The piezoelectric devices are assembled by embedding the ZnO films in polymethylmethacrylate (PMMA) and using Au thin layers as electrodes in two different configurations, namely laterally and vertically contacted devices. We present the response of the laterally connected devices as a force sensor and the characterization of the vertical devices in cantilever reaching power densities as high as 0.27 μW/cm2. Besides, we analyze their actual-scenario performance and durability by activation with a fan and under handwriting.

3. Hybridized nanogenerators

When: 2022-06-22, 11:28 - 11:35, Where: Poster session

Green synthesis of flexible, slippery and transparent fluorinated-PDMS coating by spontaneous polymerization for TENG and solar cell integration

3. Hybridized nanogenerators

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Abstract text: Solar cells are promising devices for sustainable solar energy harvest, but their performances are dramatically reduced on rainy days. On the other hand, a liquid-solid triboelectric nanogenerator (TENG) device could harvest blue energy from raindrops efficiently, which has the potential to integrate with solar cell systems to realize power generation from both sunlight and raindrops. One of the challenges for solar cell-TENG integration is the design of the solid substrate for the TENG device. This insulating layer needs to have excellent contact electrification properties and be transparent in order not to affect the light transmittance for the solar cell system. Here, we report the fabrication of a controllable liquid-like fluorinated poly(dimethylsiloxane) brushes on cellulose acetate surfaces (PDMS@CAS) through spontaneous polymerization of dichlorodimethylsilane (DMDCS) without the involvement of toxic solvents. We highlight a fast, easy, green, and universal preparation method for fluorinated PDMS@CAS coatings that are hydrophobic, long-term stable, robust, and UV-resistance. Drops of a variety of liquids slide off at tilt angles below 3° and dynamic contact angle hysteresis less than 10°, endowing the solid substrate with strong self-cleaning ability. In addition, the fluorinated PDMS@CAS equipped with the conductive polymer film PH 1000 constituted a transparent TENG device with a light transmittance of over 90%. When the TENG is integrated with the solar cell, the maximum voltage of the capacitor is near-linearly increased from 0.5 V to 0.75 V owing to the TENG with a high voltage output could compensate for the limitation of the solar cell.

When: 2022-06-20, 11:28 - 11:35, Where: Poster session

Self-Adapting and Self-powered Sensors Based on Electrochemical-Triboelectric Hybridized Mechanism

3. Hybridized nanogenerators

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Abstract text: In the coming era of internet of things (IoT) and artificial intelligence, the huge demand of high-quality sensors with features like self-powering, self-adapting, resolving complex stimulus and easy signal processing are forecasted. To endow sensors with multiple functions, integration of multiple sensing elements or adopting multiple sensing principles are required. However, for most multi-functional sensors, shortcomings such as complicated structure, complex operation and slower data acquisition, etc. still block their widespread application. Here, we report a new type of self-adapting and self-powered sensors with compact structure and multiple functions based on electrochemical-triboelectric hybridized mechanism. The sensor simply comprising of two electrode and a single-ion conducting electrolyte layer can generate both a DC (electrochemical) output up to 0.5V and AC (triboelectric) output over 2V of amplitude, and thus sensitively enable it to response to static stimuli, dynamic stimuli and environmental humidity simultaneously. This new design of versatile sensors is promising for significantly simplify the fabrication or operation of sensors while enables multiple function of a single sensor in future electronic devices and smart systems.

Self-powered Medical Devices and Electrical Stimulation Therapy

3. Hybridized nanogenerators

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Abstract text: Electrical activity is the basis of human life activities. Regulating electrical activity changes the excited and inhibited states of cells, tissues and organs to treat diseases. Nanogenerators are the new type of energy conversion device that convert low-frequency mechanical energy into electrical energy. In addition, it has gained the attention of researchers because of the flexibility, spinnability, high-output voltage, structural and material diversity. We employed nanogenerators to efficiently convert the mechanical energy of human motion into electrical energy and supply power to electrical stimulation devices and biosensors. Then, we developed self-powered electronic medical devices and medical sensors to carry out more systematic research work. For example, the power generated from the heartbeat can be used to drive the cardiac pacemaker to work for a long time, construct symbiotic cardiac pacemaker, as well as complete the research on improving heart rate and treating arrhythmia in the large animal experiments for the first time. Degradable self-powered electrical stimulation devices are used to regulate the growth direction of nerve cells, enhance intercellular integration and regulation of cardiomyocytes, promote osteoblasts proliferation and differentiation, accelerate skin wound healing. Besides, the devices can be completely absorbed by the body after the disease treatment. There are researches on self-powered cardiovascular biosensors that can realize minimally invasive implantation and have good biocompatibility. These researches focus on self-powered electronic medical devices and electrical stimulation therapy, and have important potential to be transformed into electronic medical devices and medical sensors for clinic treatment.

Synergistic Energy Harvesting by Composites of Flexoelectric Zn:Al-LDH Nanosheets and Piezoelectric MAPbI3 and ZnO Films

3. Hybridized nanogenerators

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Abstract text: We report the zinc/aluminum layered double hydroxides (Zn-Al:LDHs) nanosheets (Ns) that were most facilely synthesized at room temperature *via* an environmentally friendly process and demonstrate their ability to convert mechanical deformation into an electrical stimulus by flexoelectricity. The 1 μm-thick Zn-Al:LDH nanosheets were most facilely synthesized for 2h at room temperature after dipping the Al(10at%)-doped ZnO (10AZO)(60 nm)/Au (10 nm)/10AZO(30 nm)-coated PET samples into the carbonated water that the CO_2 in air was naturally captured in the water at room temperature. Based on the nanogenerators fabricated *via* facilely synthesized nanosheets, the output power generated from the LDH nanosheet-based generators *via* a pushing shows higher performance than that from state-of-the-art flexoelectric PZT-MWCNT-based and piezoelectric $BaTiO_3$ nanotubes-based generators. The enhanced output power was observed by the heterostructures of flexoelectric LDH Ns and piezoelectric $MAPbI_3$, ZnO films. We can also enhance the output power using the heterostructure of LDH Ns and ZnO nanorods. These findings could pave the way to the practical exploitation for environmentally friendly synthesis of LDH nanosheets using the CO_2 in air and for harvesting the energy *via* LDH nanosheets-based generators.

4. Piezotronics and piezo-phototronics

When: 2022-06-22, 11:35 - 11:42, Where: Poster session

Enhancement on Degradation of Organic Dye through Piezophototronic Activities by High Entropy Oxide-(CaZrYCeCr)O2 / Bi4Ti3O12 Nanocomposite

4. Piezotronics and piezo-phototronics

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Abstract text: High entropy material demonstrates several effects from multi-component composition, which is potential in the catalytical field. During this decade, combining the mechanical force-driven piezoelectric/ferroelectric catalysts with photocatalysts has attracted much attention due to the separation of photogenerated carriers, leading to synergistic catalytic activities. This study reports a novel composite of high entropy oxide $(CaZrYCeCr)O_2$ with unique ferroelectric properties mixing with bismuth titanate ($Bi_4Ti_3O_{12}$) microplates, improving the piezo-phototronic catalytic activities. The results show that high entropy oxide catalyst $(CaZrYCeCr)O_2$ mainly consists of the porous structure with multivalent transition metal substitution, contributing to severe lattice distortion. Consequently, the precipitation of disordered phase $Ca(Zr_{1-x}Cr_x)O_3$(x=0.1~0.2) caused by lattice distortion was decorated on the porous framework. In addition, $Ca(Zr_{1-x}Cr_x)O_3$ with a non-centrosymmetric structure exhibits ferroelectric property and plays a vital role in separating the electron-hole pairs, which performs higher degradation efficiency around 588 % compared to pristine $ZrYCeO_2$. Additionally, the ferroelectric $Bi_4Ti_3O_{12}$ was considered to construct a Z-scheme catalytic activity and form a heterojunction high entropy oxide. Furthermore, we demonstrated that morphotropic phase boundaries between $Bi_4Ti_3O_{12}$ and $CaZr_{1-x}Cr_xO_3$ could dramatically enhance the ferroelectric property and promote the performance of the piezo-phototronic activities, revealing that $CaZrYCeCrO_2$/ $Bi_4Ti_3O_{12}$ could be an innovative catalyst in the future.

When: 2022-06-22, 11:21 - 11:28, Where: Poster session

High Resolution Intelligent Tactile System Based on Piezo-phototronic Effect

4. Piezotronics and piezo-phototronics

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Abstract text: Functional tactile sensing device is a challenge for next-generation robotics and human-machine interfaces since the emulation of touching requires large-scale pressure sensor arrays with high-spatial resolution, high-sensitivity, and fast-response. High resolution tactile sensors combining the advantages of organic-semiconductor and the piezo-phototronic effects of ZnO nanowires were researched to solve the problem. The ZnO/p-polymer pn junction LED is used as the pixel point of pressure sensing. The pressure distribution on the whole device plane can be obtained by the light intensity distribution of nanowire arrays. Finely, a flexible pressure distribution sensor array with spatial resolution of 1.5 μm and optical signal sensing was fabricated. Replacing the pressure distribution of electrical signals with optical signals can instantaneously achieve large area and high integration of signal output and eliminate cross-interference. Moreover, in order to meet the needs of intelligent robots,the multi-function tactile sensors and a real-time reading/feedback controllable system were studied for intelligent manipulator application. The prepared intelligent tactile system applied to intelligent manipulator fingers, possess high sensitivity and a large range of detecting pressure. In the grip system, force distribution at each figure, different grip coefficient and material of the objects have been investigated and analyzed to achieve the intelligent operation of an artificial robotic manipulator. This type of intelligent manipulator with high-quality of the grip perception and grasping control will lead to stable and effective grasping and accomplishing the complex tasks.

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